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CALIFORNIA DEPARTMENT OF CONSERVATION
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SPECIAL REPORT 163

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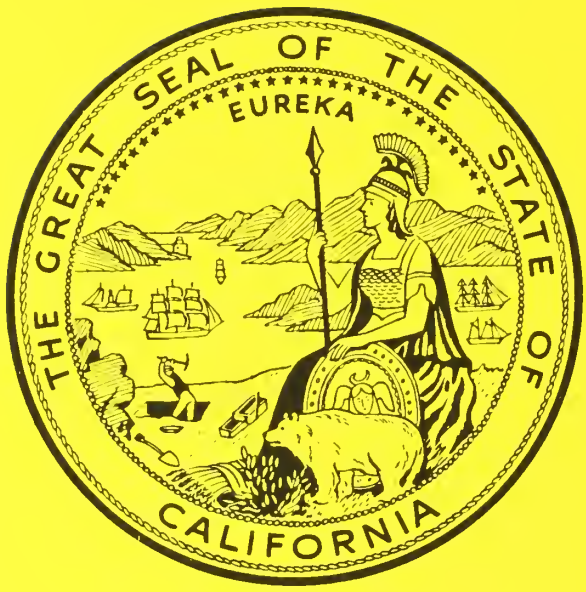

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS
STATE GEOLOGIST

Special Report 163

SURFACE AND GROUNDWATER MANAGEMENT IN SURFACE MINED-LAND RECLAMATION

By

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State Water Resources Control Board, Sacramento

and

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1989

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CONTENTS

Page

EXECUTIVE SUMMARY v

CHAPTER 1: INTRODUCTION 1

Purpose of Report 1
Planning with SMARA 1
Coordinated Hydrologic Planning 2

CHAPTER 2: THE HYDROLOGIC CYCLE 3

Precipitation 3
Temperature 5
Interception and Evapotranspiration 5
Infiltration 5
Surface Runoff 5
Stream Processes 5
Sediment and Gravel Replenishment 6
Groundwater Processes 6

CHAPTER 3: RECLAMATION PROCEDURES TO MITIGATE HYDROLOGIC ENVIRONMENTAL PROBLEMS 7

Reclamation Measures to Manage Waters Containing Unwanted Chemicals 7
Leachate from Tailings, Waste Rock and Overburden 7
Nature of Leachate Waste Problems 8
Reclamation Measures for Leachate Problems 8
Capping and Shaping of the Disposal Site 9
Containment by Liners 9
Treatment Process 11
Example Contaminant Control Approaches 11
Dewatering Wash and Processing Water 11
Storage and Handling of Processing Chemicals and By-products 12
Integration of Waste Disposal Site Selection, Processing and Disposal Methods in Reclamation Planning 12
Reclamation Measures to Protect Hydrologic Processes on the Mining Site 12
Runoff Control to Mitigate Erosion and Leachate Problems 12
Waste Containment by Damming 13
Containment by In-pit Storage 13
Control Structures to Mitigate Erosion and Sedimentation 13
Revegetation 13

CHAPTER 4: WATER-RELATED RECLAMATION ISSUES ASSOCIATED WITH SAND AND GRAVEL MINING 15

Hillside and Pit Mining 15
Reclamation Issues for "Dry" Operations 15
Operations below Seasonal High Water Table 15
Recreational/Residential Lakes 16
Water Spreading and Runoff Control 16
Wildlife Habitat/Open Space 17
In-stream Sand and Gravel Mining 17
Problems and Positive Hydrologic Effects of In-stream Mining 17
Changes in Water Flows and Storage 18
Flood Flows and Potential Flood Control Benefits 18
Groundwater Effects of In-Stream Mining 18
Stream Erosion and Sediment Yield 20
Sensitive Stream Conditions 20
Example Erosion Patterns 21
Reclamation Treatments to Reduce Erosion 22
Grading Techniques 22
Timing 23
Cross-Sectional Grades 23
Longitudinal Grades 23
Structural Measures 23
Other Hydrologic Effects of In-Stream Mining 24
Turbidity/Siltations 24
Gasoline/Oil 24
Aquatic Riparian Habitat 24
Data Needs for the Selection and Design of Reclamation Treatments 24
Small, Single-Site Operations 25
Large or Numerous Operations on the Same Watershed 25

CHAPTER 5: DATA SOURCES AND ANALYSIS METHODS 27

Data Sources and Data Collection Concepts 27
General Data Sources 27
Delineation of Watersheds 27
River Stage and Discharge Data 27
Sediment Transport and Replenishment Rate 30
Groundwater Data 30
Hydrologic Analysis Methods 31
Design Storm Selection 31
The Rational Runoff Method 32
The SCS Runoff Method 32
Flooding Evaluation 33
Hydrograph Development 33
Streamflow Changes Due to Channel Alterations 34
Slope Erosion 35
Sediment Transport/Sand and Gravel Replenishment Models 35
Groundwater 36
Computer Modeling 36

REFERENCES 37

FIGURES

Figure 1. The hydrologic cycle 3

Figure 2. Distribution of mean annual precipitation levels in California 4

Figure 3. Aggregate production versus streambed lowering, 1948-1975, in Yolo County, California 6

Figure 4. Influence of streambed lowering on recharge when a clay layer is present 19

Figure 5. Influence of streambed lowering on loss of groundwater storage during spring high water table 19

Figure 6. Headward erosion and scour resulting from single deep pit in stream channel 20

Figure 7. Headward erosion and scour resulting from single, linear, shallow pit in stream channel 20

Figure 8. Headward erosion and scour resulting from two in-line pits in stream channel 21

Figure 9. Headward erosion and scour resulting from two offset pits in stream channel 21

Figure 10. Headward erosion and scour resulting from deep pit in stream channel 22

Figure 11. Headward erosion and scour resulting from shallow, elongate pit in stream channel 22

Figure 12. Longitudinal profile showing migration of a sand-and-gravel pit knickpoint in San Juan Creek, Orange County, California 23

Figure 13. Areal designation of major drainage areas for California 28

Figure 14. Index to the Township and Range System 29

Figure 15. Hypothetical alteration of runoff (watershed) area due to development of the surface mine 30

Figure 16. Rainfall intensity plotted against duration for different recurrence intervals 32

Figure 17(a). Typical storm-runoff hydrograph 34

Figure 17(b). Idealized triangular hydrograph 34

TABLES

Table 1. Reclamation techniques for sulphide waste 10

Table 2. Countermeasures for stream erosion 23

Table 3. Infiltration capacity ranges for SCS soil groups 33

EXECUTIVE SUMMARY

The California Surface Mining and Reclamation Act of 1975 places a strong emphasis on hydrologic issues associated with the reclamation of mined lands. Other regulations in the Water Code and the Health and Safety Code affect surface mining operations under some conditions. The purpose of this document is to provide information on surface and groundwater management for the mined-land reclamation process. It describes issues, data and methods of analysis for minimum assessments of water-related impacts. Where significant potential effects are identified, special studies and designs may be needed; in such cases, special expertise in hydrology, geology and engineering will be required.

There are a number of local, state and federal agencies that collect information on hydrologic processes that can affect reclamation planning. The California Department of Water Resources has published "Index to Sources of Hydrologic Data," Bulletin 230-81 (1981), and has data collection branches in its district offices in Los Angeles, Sacramento and Red Bluff. Annual updates of hydrologic data sources are available on microfiche at each district office. Because hydrologic analyses generally require data for periods of many years, it is always valuable to use data from existing sources where possible, even if they must be supplemented by site-specific data. Hydrologic conditions in California are so varied that a site-specific data collection program often must be included in the planning process.

Hydrologic analysis of watershed runoff, stream channel flow and erosion are particularly important. The effects of changes within the mining site often extend both upstream and downstream from the site itself. There are simple methods for preliminary analysis, but more detailed analysis is increasingly done using computer models.

The surface runoff-erosion process not only creates sediment and turbidity problems, but exposes soil and waste rock to leaching of chemicals that may contaminate surface water or groundwater. Diversion of runoff around the site and containment of runoff on the site are normal reclamation processes. Lined ponds may be needed for some waste water. Careful planning of surface changes during the mining operation can reduce the surface runoff problems.

In-stream sand and gravel mining presents special problems because the stream channel is modified directly. At high flood flows, the changes in the channel may direct the erosive power of the stream against the bed or banks in areas not recognized in a low flow analysis. The pits from the mining operation may also modify the sediment transport process and local channel slopes, and in this way, too, influence channel erosion.

This document is not a handbook for complete analysis of water management issues, but a guide to aid the planner and the plan reviewer in finding the information to assess the potential impacts and possible control measures.

CHAPTER 1: INTRODUCTION

Purpose of Report

The purpose of this report is to provide information on surface water and groundwater management for use in the mined-land reclamation planning process in California. Mined-land reclamation, as defined in the California Surface Mining and Reclamation Act (SMARA), is the combination of land treatments which prevent or minimize water degradation, air pollution, damage to aquatic or wildlife habitat and erosion resulting from a surface mining operation. Possible users of the information include lead agency representatives (cities and counties having regulatory authority under SMARA), the mining industry and their consultants, the public and those in local, state and federal agencies who may serve as advisors and/or regulators.

Surface water and groundwater management plays an integral role in virtually every reclamation plan. Groundwater and surface water runoff (both onto and off of the site) must often be evaluated: (1) to design flooding and erosion protection measures such as drainage channels, levees, culverts or riprap; (2) to prepare and carry out a successful revegetation program; (3) to design stable final slopes; (4) to maximize potential available water for the operation and reclamation stages; (5) to prevent the discharge of contaminants from processing or disturbed areas; and (6) to limit long-term leachate formation and movement from tailings, pit or waste rock disposal areas.

Many subsequent use selections, including commercial, residential, agricultural and open space uses, incorporate aspects of water management as focal points in the development of the mined land for its final use. Residential lakes, water-based recreation facilities, aquaculture, wastewater disposal systems, aquatic/wildlife refuges, flood control and groundwater recharge facilities can be viable subsequent use choices for surface mined areas. Selection and design of these uses for any one site, however, will depend on the site's groundwater and surface water characteristics. This report provides a fundamental understanding of the hydrologic processes that need to be considered in the design for these subsequent uses. In doing so, it also provides a baseline inventory of concerns that need to be addressed to prevent or minimize adverse environmental effects of mining (SMARA, 1975, Section 2712).

Recognizing that mine operators and local government personnel who prepare and review mining applications and reclamation plans cannot be expert in all the subjects that must be considered, the Department of Conservation's Division of Mines and Geology is publishing a series of guidance reports. This report is intended to help mine operators initially appreciate the hydrologic issues important in the development of a successful reclamation plan. The operator can use these insights in working with consultants who may prepare the details of plans, and with local governments that must approve the plans. For local government, the intent is to assist in exploring hydrologic issues with the mine operator, so that both can be confident of the potential hydrologic impacts of the mining operation. While the report may help in identifying issues affecting mining operations, it is not intended to address operating aspects except as they may affect reclamation planning. Since monitoring during the reclamation phase will usually be a partial carry-over from the operating plan, this report does not provide specific monitoring guidance.

An overview of the hydrologic cycle is presented in the next chapter to point out component processes that are likely to be affected by mining operations, or that are likely to affect the reclamation planning alternatives. Many of the hydrologic processes are fundamental not only to surface water and groundwater management, but to other aspects of reclamation planning. For example, revegetation in the reclamation planning process is dependent upon both a stable, non-eroding planting surface and the proper moisture (climatic) conditions at the reclamation site. Landshaping to insure slope stability and control erosion must include consideration of the site's surface water and groundwater conditions.

Chapter 3 discusses hydrologic reclamation issues in relation to impacts that may be created by mining operations. The issues in Chapter 3 may come from any kind of surface mining activity. Chapter 4 focuses on sand and gravel operations, a major part of the surface mining in California. Hillside and in-stream sand and gravel mine reclamation are discussed separately because each presents several unique subsequent use possibilities and reclamation concerns.

The types of data and methods of analysis for hydrologic issues are presented in Chapter 5. Some sources of data and simple analysis methods are described, but details of data collection procedures and hydrologic analyses for complex projects should be left to experienced hydrologists. Hydrologic manuals and other publications have been referenced throughout the report to provide users with additional sources of information on what are often complex and highly technical elements of hydrologic reclamation planning. Many of the references used in this report have been annotated in the Division of Mines and Geology publication, "An Annotated Bibliography of Publications Pertaining to Surface Mined-Land Reclamation" (California Division of Mines and Geology, 1984).

Although an attempt has been made to minimize the use of technical jargon in this report, the reader will find a number of cases where the technical terms have been retained. The Division of Mines and Geology publication, "A Glossary of Surface-Mined Reclamation Terms" (California Division of Mines and Geology, 1984b), may be consulted for definitions of terms.

Planning with SMARA

SMARA places a strong emphasis on hydrologic issues associated with the reclamation of mined lands. The act calls for reclamation of surface mining operations that minimizes water degradation, flooding, erosion, sedimentation and damage to aquatic habitat (SMARA Sections 2733 and 2722). Careful reclamation planning, information gathering and comprehensive site evaluation by the mining industry has, in many cases, not only avoided adverse hydrologic impacts, but has identified steps to improve existing undesirable situations.

Development of a water management program in the reclamation planning process can help to achieve quality and quantity goals and to speed the project through the permit process. The compilation of sufficient hydrologic baseline inventory and monitoring data will also help to restrict unreasonable allegations of water quality degradation.

Coordinated Hydrologic Planning

Agencies that will be involved in the review and regulation of water management aspects of a site's reclamation should be contacted early in the mine operational and reclamation planning process to establish the most efficient and economical means of data collection and analysis. If the reclamation planning team can coordinate its efforts in the initial stages of data collection, the data collection systems and data analysis can be designed to maximize information useful to the determination of successful reclamation treatments. For instance, if a recreational lake is being proposed as part of a residential subsequent use, it will be important to determine annual and seasonal variations in climate, groundwater levels or surface water inflows to the lake in order to design the shape of the lake shore, depth and access. If widely fluctuating water levels are not taken into account in the reclamation of the site, there may be unsightly mudflats which limit recreational use of the lake, or conversely, the residential areas and surrounding lands may be subject to flooding. The type of data needed to design lake shore shaping, runoff control, outlet structures, etc., is often collected in response to, or in conjunction with, various agencies' requirements. Thus, the sooner these requirements are known, and the reclamation planning process begun, the more successful reclamation planning will be.

Several state agencies have regulatory authorities that may be involved in surface mining and reclamation. The diversion or storage of water from surface streams is subject to water rights regulation by the State Water Resources Control Board, even if it is not specifically for the use of the water as a supply. There is no general regulation of groundwater withdrawals, but state law does provide for cities, counties, and some water districts to adopt well-drilling regulations. A Model Well Ordinance is currently being reviewed for adoption by the State Water Resources Control Board. The storage, handling, and disposal of hazardous substances is regulated by the Department of Health Services. Disposal of substances that could potentially degrade either surface or groundwater is the responsibility of the State Water Resources Control Board and the Regional Water Quality Control Boards.

The storage and disposal of water containing toxic substances or the handling of toxic processing chemicals is regulated by the Regional Boards and the Department of Health Services. Most in-stream mining activities have potential water quality effects that concern the Regional Boards. If fish or their habitat may be affected, the Department of Fish and Game has authority that is regulatory. For example, Section 1505 of the California Fish and Game Code vests the Department with power to "manage, control and protect" fish spawning areas in a number of specified rivers in California. When dams are used, the Department of Water Resources, Division of Safety of Dams, may be involved for dam safety considerations, depending on the height of the dam or the size of the impoundment created.

Many federal agencies delegate authority to state agencies, but the U.S. Army Corps of Engineers has permitting authority for activities that can affect navigable waters or their tributaries. Section 404 of the Federal Clean Water Act (PL 92-500), for example, authorized a permit program for any discharge of dredged or fill material into "the waters of the United States." Thus, dredging or mining operations in or adjacent to streams or wetlands that are classified as navigable may require the Corps permits. Agencies or mine owners/operators should contact the appropriate Corps of Engineers District Engineer.

Most of these agencies welcome early contacts and will help the operator determine if formal applications are needed. If there is any possibility of the regulations coming into play, consultation and coordinated planning should be started early in the process.

In addition to specific regulatory and management authorities, the various local, state and federal agencies are subject to the California Environmental Quality Act and the National Environmental Protection Act in approving applications. Mine operators should recognize the need for environmental impact assessments and the time needed for the review process. Again, early contact with agencies is advisable.

CHAPTER 2: THE HYDROLOGIC CYCLE

The hydrologic cycle, shown in Figure 1, represents the ways in which water is circulated from the earth's atmosphere over and through the ground surface and back again. Solar radiation evaporates water from the earth's surface. This moisture, under the right temperature and pressure conditions, forms clouds and begins to precipitate, primarily as rain and snow. Precipitation is captured on leaves and branches of vegetation, from where it can be evaporated or fall to the ground. There it can accumulate on the surface, evaporate, infiltrate into the ground or run off over the soil. Runoff is channeled into rills, gullies, streams and rivers leading eventually to the ocean. It can also be captured along the way by depressions, infiltrated into the soil or evaporated back into the atmosphere.

Water that enters the soil can be taken up by vegetation, stored in pores or fractures in subsurface material or move down to the saturated zone, where it joins groundwater. Groundwater, in turn, can supply water to vegetation or to streams, lakes and oceans to be eventually evaporated and begin the cycle again.

Surface mining can affect many aspects of the hydrologic cycle. By nature, surface mining involves the removal of vegetation and overburden; pitting, reworking or reshaping the land surface, waste rock and overburden; and disposal of tailings and processing materials. These activities can influence interception, evapotranspiration, runoff, infiltration, groundwater recharge and water quality.

Precipitation

Although mining operations do not affect it, precipitation is a key element of the hydrologic cycle in reclamation planning. It is the primary input for surface water processes and has a direct effect on soil erosion. Fundamental evaluations of mine site revegetation and long-term slope stability also depend on knowledge of the precipitation. The severity of many mining impacts depends on the amount, form and timing of precipitation.

Most of California receives precipitation in cyclic patterns of wet winters and dry summers, although there are exceptions such as desert areas that record maximum monthly precipitation in the summer (California Department of Water Resources, 1981a). In many areas, rain and snowfall are strongly influenced by latitude, longitude and elevation. The areal variability can be seen in Figure 2, which depicts mean annual precipitation for California. The influences of mountain ranges are indicated by the concentric shape of the isohyets (contours of equal

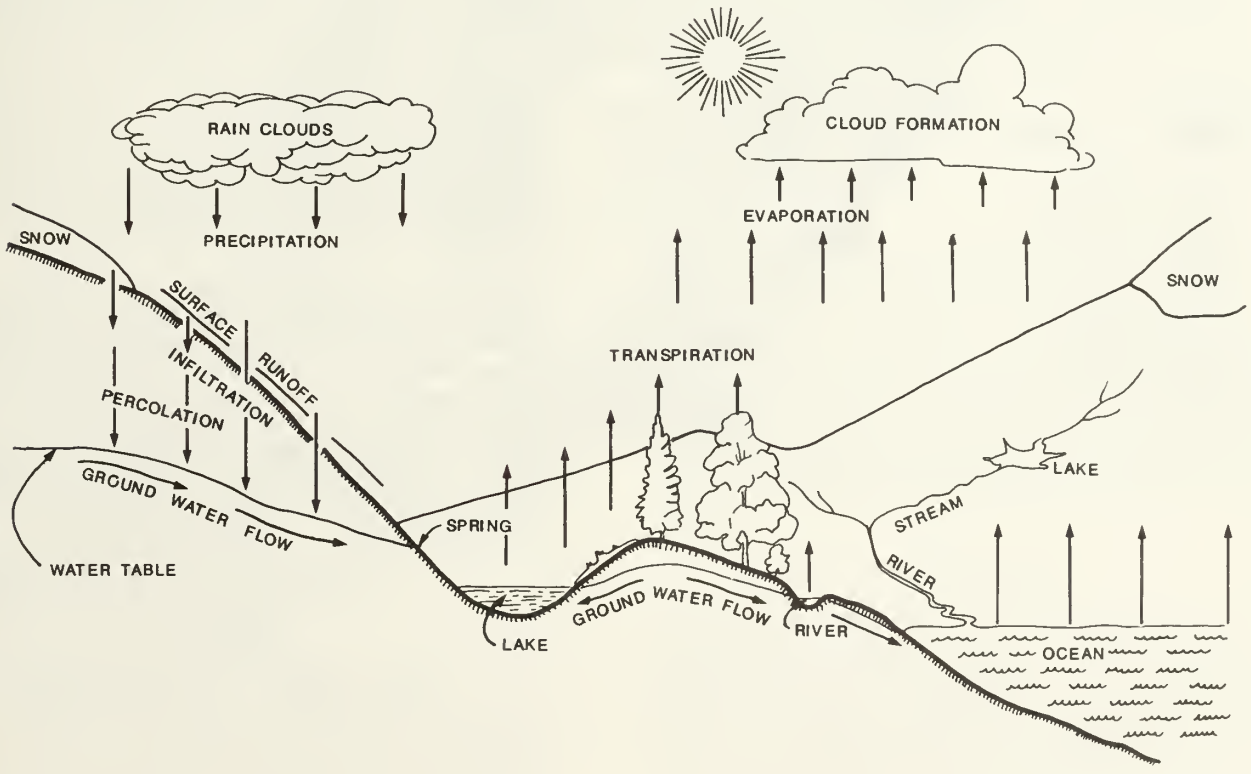


Figure 1. The hydrologic cycle.

rainfall). The orographic process, in which precipitation is controlled by land elevation, is common in the mountainous areas of California. This process is responsible not only for the generally higher precipitation found on the western side of most California mountain ridges, but for the "rain shadow" on the eastern side, particularly along the Sierra Nevada. Once over the crest of the ranges, the air temperature and pressure increase, and rain is less likely to fall.

On a local scale, the effects of ridge and valley shapes can also be significant. The climatic station that is closest to a mine site may not be the most representative of site conditions. Thus, when specific hydrologic data is collected for a reclamation program, climatic data from several storm events or seasons should be taken at the proposed mine site and compared to several nearby climatic stations to determine which, if any, may indicate long-term conditions at the reclamation site.

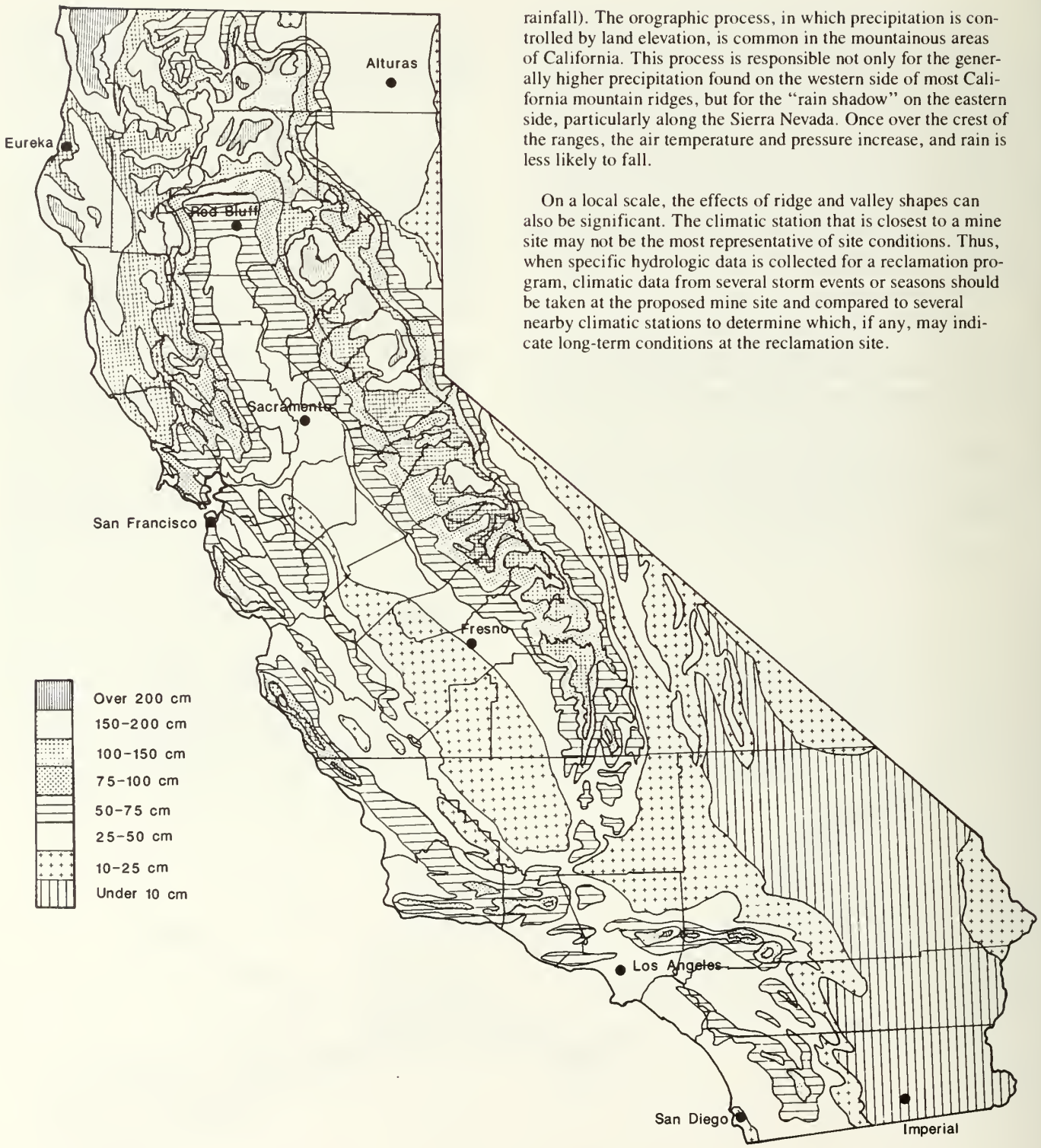


Figure 2. Distribution of mean annual precipitation levels in California. *Modified from California Department of Water Resources, 1981b, Rainfall depth-duration frequency for California: California Department of Water Resources, Sacramento, California, December 1981, 38 p., plus 21 microfiche.*

Temperature

Mining operations can affect local temperatures enough to cause significant problems for plant and animal life. By removing vegetation and overburden that provide shade and soil moisture, the mining operation can lead to increased air and upper soil temperatures. If vegetation is removed from stream banks, the water temperature may be raised enough to affect fish.

The range and potential variability of the temperature at a mining site is important to the evaluation of the revegetation potential, erosion processes and water quality. Higher temperatures increase both evaporation from water surfaces and transpiration, the process by which plants transfer water to the atmosphere. Lower temperatures can cause freezing and thawing, which affect soil infiltration, seed germination, plant growth and soil erosion. Areas that receive significant amounts of snow will have different runoff characteristics than those that receive only rainfall. Soil temperatures may vary significantly over a site due to slope aspect and color of the surface material. If so, the vegetation growth will be influenced, and revegetation may have to be tailored to specific conditions. (Revegetation is the subject of a separate report: Van Kekerix and Kay, 1986.)

Interception and Evapotranspiration

Interception is the capturing of falling precipitation by vegetation and subsequent evaporation of the moisture back into the atmosphere. Heavily vegetated areas can intercept significant amounts of precipitation, reducing the quantity available for runoff or infiltration. Interception is a function of the vegetation type, density, form and age (Dunne and Leopold, 1978).

Evapotranspiration is the combined loss of water evaporated from the soil surface, ponds, lakes and rivers, and that water transpired (transferred to the atmosphere) by plants. Evapotranspiration depends on the area of water or wet land surface, the type and condition of vegetation and the air temperature and wind speed.

These processes are affected by both the removal of vegetation during mining and the type or amount of revegetation carried out during reclamation. An understanding of the site's interception and evapotranspiration allows an estimation of the hydrologic balance before and after mining. Adjustment of these factors in reclamation can beneficially affect the related runoff and percolation characteristics. For instance, some types of revegetation over a tailings area could increase both interception and evapotranspiration of that area. Revegetation will decrease the amount of precipitation that can percolate into the tailings material, and thereby reduce the amount of leachate that could be produced.

Infiltration

The amount of precipitation that becomes surface runoff is controlled by the infiltration rate. Infiltration is the movement of water from the soil surface into the ground. It is affected by the slope of the soil surface, the characteristics of the surface, the permeability of the soil, the surface cover and the amount and intensity of rainfall. The water that infiltrates may be used by plants, re-surface at lower elevations or percolate down to groundwater.

Mining activities can affect infiltration when the overburden is removed, reworked, amended, replaced and recompacted. During these operations, basic soil structure and permeability are commonly altered. This can affect not only the quantity and distribution of site runoff, but erosion rates, potential leachate production, groundwater recharge and revegetation potential. If appropriate reclamation techniques are applied, many or all of these modifications can be beneficial. Reduced infiltration resulting from the removal of vegetation and increased impermeable surfaces during mining can increase the fraction of rainfall or snowmelt that moves as surface runoff. If leaching of contaminants is a problem, the reduced infiltration can be beneficial. If the end use of the site requires more infiltration, much of the vegetation can be replaced, and compacted areas can be ripped or excavated to restore infiltration capacity.

Surface Runoff

The water that runs off across the surface of the ground quickly collects in rills and then into defined stream channels. The rate at which water flows is a function of the slope, the roughness of the surface and the depth of flowing water. Thus, the water in the rills and stream channels moves much faster than that spread over the surface as sheet flow. The rate or velocity of the surface runoff affects the erosion of the soil surface. The rate at which the water reaches a stream affects the stream-flow rate and the stream's sediment transport capacity.

During surface mining operations, the land slope and soil surface conditions are altered extensively. The velocity of the surface runoff may be increased or decreased by these changes. The kinds of chemicals the surface runoff encounters and dissolves are affected by the surface changes and the location of mine tailings storage or disposal areas. Thus, the changes that are made to surface runoff during the mining operation, as well as in the reclamation phase, need particular attention during the planning process.

Avoidance of detrimental changes is best achieved by understanding existing drainage conditions at a site. Where topography is not significantly altered, mimicry of existing patterns may present the least difficulties. Where significant change to the original site is anticipated, it may be necessary to complete a hydrologic analysis of surface runoff. Mitigation measures for potential problems identified in the analysis should be designed to insure that erosion and flooding do not result from the newly established drainage system. Numerous textbooks and articles are available to help achieve these goals — for example, Dunne and Leopold (1978), Schumm (1977) and Morisawa (1968).

Stream Processes

Streams and rivers are said to be in "dynamic equilibrium," which means that changes in one portion of the system often lead to effects in other areas that were not initially disturbed. In a short-term analysis, the channel's longitudinal slope, cross-section area, roughness or resistance to flow and depth of flow, control the velocity of flow and capacity for water discharge. The water velocity and discharge, in turn, determine the sediment transport capacity and the erosive potential of the stream. In a long-term view, the water discharge, sediment load and related factors affect the channel slope, cross-section shape, roughness, etc.

Mining operations can affect stream processes both directly and indirectly. In-stream mining has obvious direct effects. Excavation can create new flow paths and access ramps can obstruct existing channels. A stream may be leveed to go through a mining site, changing the slope and other factors. Indirect effects may include changes in the amounts of and locations at which water and sediment enter the stream. The stream responds to the direct and indirect changes by modifying the flow conditions in the immediate area, and possibly both upstream and downstream. The adaptions that the stream system will make are not always obvious. In recognition of the possible effects outside the mining site, SMARA (Section 2770.5) requires that the Department of Transportation be contacted when operations will be within one mile upstream or downstream from a state highway bridge.

A complicating characteristic of stream processes is the large variability in flow. Flows may range from zero in summer and early fall to extreme flood flows that occur only once every several years. A reclamation approach that works well at one flow rate or level may be harmful at another. For example, a channel carrying the stream along the side of a mining site may be useful at low flows. But a flood flow might accelerate erosion of the bank along the side or might totally wash out the control channel. It is important to recognize both the "dynamic equilibrium" and the variability characteristics when planning the operation and reclamation of mining sites.

Sediment and Gravel Replenishment

Surface mining operations can alter the rate of sediment replenishment to a stream or, in sand and gravel mining, remove material faster than it is replenished. Too great a reduction in the replenishment or too fast a removal can lead to erosion problems. Several watershed studies have documented cases of significant erosion where cumulative extraction far exceeded the estimated replenishment rate. A record of extraction versus streambed lowering in Yolo County is shown in Figure 3. Further problems may develop as a stream adjusts to the lower bed level. In-stream operations need to take special note of the balance between mining and replenishment.

The sediment in a channel may be the culmination of hundreds or thousands of years of sediment transport and deposition. California's rainfall is so variable that river flow over only a few seasons or years may not provide an accurate picture of historic or future sediment transport. Data collected in northern California from 1975-80, for example, is strongly influenced by the 1975-76 drought, and would indicate a lower discharge and rate of sediment transport than that from a more "wet" period, such as 1980-85. The effect of a short period of record is especially limiting in gravel replenishment considerations. Very often, the largest transported material (gravel, cobbles, etc.) is supplied and transported during rare storm events such as the 100- or 500-year storms. To be valid, a statistical estimate of the variability of flows or the average sediment transport must generally be based upon a data record spanning decades.

Groundwater Processes

Groundwater is often a significant factor in surface mine operation and reclamation because of the potential effects the operation may have upon the groundwater and vice versa. For instance, too much groundwater may result in water management and disposal problems. Too little groundwater may necessitate operational or make-up water from outside sources, and added expense. Poor quality groundwater may limit subsequent use possibilities such as recreational lakes, water supply or aquaculture. Near-surface groundwater may dictate waste disposal practices or potential final ground surface elevations for alternative end uses. Water supplies must be protected from chemical and biological contaminants. Thus, for many surface mining operations and their reclamation, it is important that accurate estimations of water quality, quantity and movement be made.

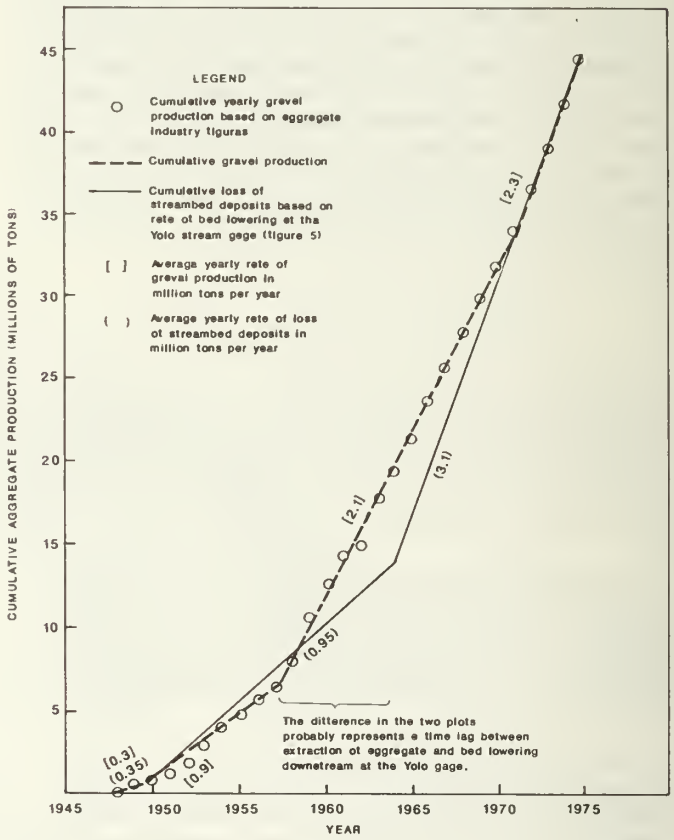


Figure 3. Aggregate production versus streambed lowering, 1948-1975, in Yala County, California. *From Woodward-Clyde Consultants, 1976, Aggregate extraction management study, County of Yolo, California: Prepared for the County of Yolo Planning Department, Aggregate Resources Management Committee, 128 p.*

The groundwater movement and processes are often complex. A single site may have several aquifers underlying it, each with different water quality characteristics, or it may have no measurable groundwater at all. Groundwater elevations within a site's aquifers can vary by millimeters or meters with changing seasons. Groundwater recharge may be provided by a pond, stream or rainfall on the site, or it may come from a source miles away. These types of factors, coupled with generally limited existing data, often make accurate analysis and prediction difficult. In many operations, a site-specific data collection program is necessary.

CHAPTER 3: RECLAMATION PROCEDURES TO MITIGATE HYDROLOGIC ENVIRONMENTAL PROBLEMS

SMARA calls for state policy on reclamation of surface mined lands to include erosion control, water quality and watershed control, waste disposal and flood control (Section 2756). These issues, which concern any surface mining operation, are discussed in this chapter. Because sand and gravel mining is such a large part of California's surface mining, it will be addressed specifically in the next chapter.

In recent years, public awareness and concern regarding toxic chemicals in water has increased. This chapter starts with a discussion of the management of waters containing unwanted chemicals. The other issues mentioned above — erosion control, watershed control and flood control — are concerned with protecting or maintaining the hydrologic system processes and are discussed later.

Reclamation Measures to Manage Waters Containing Unwanted Chemicals

The proper disposal of mining waste, which "includes the residual of soil, rock, mineral, liquid, vegetation, equipment, machines, tools or other materials or property directly resulting from, or displaced by surface mining operations" (SMARA Section 2730), is one of the primary objectives of SMARA. Degradation from these sources, suspended and dissolved, can impair surface water and groundwater quality. Many of the potential detrimental effects can be mitigated, however, by selection of an appropriate end use, design of a mine waste disposal site, and treatment, placement and shaping of the mine waste during the mining and reclamation phases. Control of contaminants and disposal of all mining waste in a condition that minimizes adverse effects is required by SMARA Sections 2772(h)(1), 2730, and 2733.

Perhaps most important to the disposal of mine waste is a thorough understanding of the disposal site and how it relates to the waste to be disposed of. Reclamation techniques must be tailored to individual situations. Inadequate comprehension of the existing and proposed conditions can lead to extremely expensive water quality clean-up situations. The cost of contamination and/or treatment of contaminants once they reach either surface water or groundwater is usually far more expensive than initial treatment costs. The State Water Resources Control Board has adopted regulations that classify mining wastes and provide minimum requirements to protect water quality (Water Code, Title 23). The appropriate Regional Water Quality Control Board should be contacted early in the planning process to determine whether more stringent requirements have been set. If hazardous wastes (California Health and Safety Code, Division 20) are present, the Department of Health Services also should be contacted.

In the initial stages of disposal site investigation and reclamation planning, basic meteorologic and surface water and groundwater systems should be examined. Climatic data should be analyzed to determine the characteristics of seasonal cycles and to define rainfall intensity and volume for various reclamation treatments. Watershed areas should be delineated and runoff, infiltration and evapotranspiration estimated in order to establish a rough hydrologic budget. This information will help guide design to minimize seepage of contaminated water into surface water or groundwater systems.

Topography should be evaluated not only for estimation of potential quantities of waste storage, but for the potential for flooding, slope failure and earthquake activity that could affect the site. Water quality may be damaged not only by slow seepage from a disposal site, but also by the release of large volumes of tailings, processing water, waste products, etc., due to flooding, landslide or earthquake activity. Analysis of the general stability and flood probability should, therefore, be carried out in the initial reclamation planning and evaluation stages of mine waste disposal sites.

Where groundwater occurs, hydrogeologic work should begin in conjunction with topographic evaluation and exploration borehole and geophysical methods of evaluation. Soils should be mapped, and grain-size distribution, permeability and other engineering properties determined, so that potential long-term leakage, settlement and slope stability problems can be evaluated. If this initial evaluation indicates there may be significant engineering or hydrogeologic problems, waste disposal design solutions or alternative sites can be identified and/or incorporated into the reclamation planning process (Williams, 1974).

Delineation of fractures, faults, historical mining tunnels and landslides will also be necessary in the initial evaluation stages of the site's groundwater system. These features often play a major role in the definition of groundwater systems and can significantly influence groundwater movement. In the event that an unforeseen disposal problem occurs, this type of information will also be necessary for a speedy clean-up and recovery of contamination.

Reclamation approaches to the disposal of mining waste must be geared toward the type of waste, as well as the characteristics of the potential site. Waste characteristics may dictate special reclamation treatments, necessary design features of a potential disposal site or the need for a pre-disposal treatment facility. Major sources of unwanted chemicals may be leachate from tailings, waste rock or overburden; dewatering, wash or processing waters; and storage or handling of processing chemicals and by-products.

LEACHATE FROM TAILINGS, WASTE ROCK AND OVERBURDEN

The disturbance, exposure, breaking and crushing of waste rock and overburden can release contaminants in concentrations that may degrade existing water quality. While these substances are "natural," the rates of oxidation and weathering may be accelerated by mining to a level greater than those rates found in the undisturbed state. Tailings, usually the crushed and slurried waste of initial mineral processing, can affect water quality in several ways. First, crushing decreases the grain size of the material, increasing the surface area. This makes the material more reactive. Second, various reagents are often added to the ore to extract the mineral.

Control of the leachate resulting from these mining wastes is often a major goal of reclamation. "Leachates," as used here, means liquids that have percolated through soil, tailings, overburden and/or waste rock and contain substances in solution or suspension that can degrade both surface water and groundwater quality. Chemicals initially in the tailings moisture, in combination with products leached from the waste by infiltration of surface water or migration of groundwater, may result in heavy metal contamination, acid or alkaline discharge, and other detrimental water quality effects.

The major mechanisms working in the subsurface transport of dissolved solids from leachate are the attachment of chemicals to soil particles (sorption), dilution and bacterial action. These processes often work to eliminate or lessen impacts to water quality that might occur from leachate. Bacteria frequently use any organic material in the leachate as a food source. Inorganic material and concentrations of organic material that remains "uneaten" in the leachate will be further reduced as the leachate moves in the subsurface — the primary reduction occurring by sorption.

Sorption of dissolved solids on earth materials by ion exchange may remove a substantial portion of leachate waste from groundwater systems. Discussion by Hughes and Cartwright (1972), however, emphasizes the need to envision this process in the long-term. Where all of the ion exchange positions of the clay materials in the matrix are occupied, sorption of new ions from a leachate may result in the release of previously sorbed ions, with only minor reduction in the quantity of dissolved solids in the moving fluid. This process may result in only extending the travel time of ions that originated in the waste, and may do little for permanent disposal (Williams, 1974).

Dilution and dispersion, the weakening of the concentration and spreading of the contaminant, may be of lesser importance in the transport of some leachates, but must be understood in order to estimate or model the potential migration of a leachate from a source.

Many of the newly proposed or operating mines in California are in regions of historical mining. Highly mineralized and faulted areas, such as the Sierran Mother Lode and the East and West Shasta Districts, are seeing renewed surface mining interest as extraction technologies and mining equipment improve. Many of these newly proposed sites were historically worked as underground mines. The richest and most accessible veins were followed, creating (sometimes currently unknown) grid works of tunnels. Knowledge of these tunnel systems is important, not only for safety and operational concerns, but for an understanding of the groundwater conditions underlying the site. These tunnels, as well as the faults and fractures commonly associated with highly mineralized zones in California, often have a predominant influence on groundwater flow beneath the site.

These subsurface flow paths can move groundwater and potential contaminants at significantly higher speeds than the unfractured or un-tunneled subsurface material. Fault or shear zones can also act as barriers to movement, however. Where fault zones are weathered, low permeability materials may be formed which block or retard groundwater flow across that zone. Consideration of these types of subsurface features is, thus, often critical to short- and long-term water quality control at surface mining sites.

Noture of Leochote Waste Problems

In California, the reclamation planner may face a number of varied leachate problems, depending on the mineral deposit, the mining and processing technique and the hydrogeologic conditions. Most frequently in California mining, major leachate issues involve pH (either alkaline or acidic), cyanide, dissolved solids and heavy metals (see Buer and others, 1979, and California Regional Water Quality Control Board, Lahontan Region, 1983).

California's gold, silver, copper, lead and zinc ore bodies are frequently associated with sulphide materials, such as pyrite, that, when oxidized, produce sulphuric acid and mobilize metals. The combined effects of both low pH and heavy metals can create a serious water quality problem.

The water quality issues associated with reclamation of these types of mines are well documented, as they also are found throughout coal mining regions. Acid mine drainage commonly results from the oxidation of pyrite (iron sulphide) and elemental sulphur. When left exposed to air and moisture at the surface, pyrite and sulphuric iron produce a significant acidic influence on surface water and groundwater. Sulphur combines with oxygen in air or water to product sulphuric acid. These reactions, often speeded or caused by bacterial action, are shown below in a simple form:

(a) In a dry environment: $FeS_2 + 3O_2 = FeSO_4 + SO_2$

(b) In a wet environment: $2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$

A low pH, or highly acid condition, dissolves many minerals, producing soluble salt solutions. Metals, such as copper, zinc, cadmium and manganese, commonly associated with many metallic ore bodies, are thus dissolved and introduced into the hydrologic system (Williams, 1974).

Most fish species are adversely affected by acid conditions and by dissolved metallic compounds in the water. For example, the discharges from mine portals, open pits and mine dumps have destroyed all fish life in receiving waters in the Spring Creek drainage area above Keswick Dam on the Sacramento River. Some species — usually the most popular for sport fishing — are affected by very low concentrations of metals. Salmon and steelhead are especially sensitive during spawning.

Cyanide leach solutions are being used increasingly in California for gold extraction. Crushed ore is usually placed on a clay or synthetic liner; and a cyanide solution is allowed to percolate through the ore material, capturing gold which is later removed from the cyanide solution. The long-term disposal effects of waste resulting from this cyanide method are not well documented. As in the production of acid mine drainage, there are presumed to be many complex chemical and biological processes that may affect the transport of cyanide leachate. While information is incomplete, research on the long-term effects of cyanide mining waste disposal is being supported now by the U.S. Bureau of Mines.

Reclamation Meosures for Leochote Problems

Testing of sample leachate or estimation of potential leachate properties should be a primary step in the development of most

reclamation programs for mining waste. This testing, in conjunction with the identification of potential disposal sites, should lead to the selection of a site or identification of design features that offer the best long-term reclamation solutions.

Lee and Jones (1982), in an evaluation of hazard assessment and waste disposal, conclude that leachate testing must be specific to each site and consider such factors as: (1) the type and amount of contaminants released from the solid waste or associated liquids; (2) the load and rate of transport from a disposal site to a potential site of concern; (3) the concentrations of contaminants; and (4) the forms of contaminants at the point of concern and other related factors.

In addition, Anderson and Jones (1983) discuss the necessity of accounting for site climatic conditions in the evaluation of leachate quality. Initial liquids that are released from the waste (primary leachate) may not be similar to subsequent leachate generated by percolation of rainfall or snow melt through the waste, reacting with the minerals (secondary leachate). Leachates may also be influenced by climatic cycles of dilution by rainfall or concentration by evaporation; wastes may undergo biochemical and geochemical changes that may significantly affect leachate characteristics.

The quantity of leachate can be minimized by capping the tailings or waste rock storage area. The remaining leachate must be contained. Containment by lining the tailings area is discussed below. Containment by dams and pits, which is discussed in the section on water management, may also be used for leachates, but where other waters do not contain toxic materials, it is preferable to keep contaminated leachate separate.

Finally, it may be necessary to treat the leachate before final disposal. Some methods of treatment are listed below. When treatment is necessary, special consideration should be given to the fact that the process may have to continue as part of the reclamation effort long after the mining activity has ended.

If acidic drainage comes in contact with mine tailings, bacterial action can aggravate the problem of dissolved metals. Bacteria of the family Thiobacillus ferroxidans require a pH less than 4.5 to be a significant factor. When the pH is lower, these bacteria can be a primary mechanism in moving minerals from the tailings to the leachate. If the pH can be kept above 4.5, or the bacteria rendered inactive by an approved method such as use of detergents, this source can be minimized. The same may be said for waters released to streams: if the releases are not made when the pH
is low, there will be less increase in dissolved minerals as the stream flows over natural mineral formations and sediments.

Caution also must be used if acid-producing material is buried or stored near the elevation of a fluctuating groundwater table. The alternating exposure to air and then saturation can lead to increased acid in the leachate. The acid is produced during exposure to the air, and then flushed out during the high water period.

Capping and Shaping of the Disposal Site. Placement of a low permeability "cap" on a tailings disposal area can limit the amount of water that percolates through the tailings. Often, this cap is composed of stored topsoil or fine overburden. Primary considerations for this type of treatment include: (1) availability of the necessary quantities of a suitable capping material; (2) permeability and compaction requirements; (3) proposed revegetation needs; and (4) size and stability of the tailings material.

In many cases, the usefulness of this type of reclamation approach will be guided by the characteristics and quantity of available topping material and the rate of waste material dewatering. If too little material is available for an effective cap or compaction cannot create low enough permeability, other reclamation techniques may need to be implemented.

Smooth shaping and grading can work to promote runoff and decrease the infiltration of surface waters: the fewer depressions, the less capture and storage, and the less potential infiltration of water into the tailings material.

Sloping of the cap can add to drainage control. In many cases, small drainage channels are established on top of the cap itself to enhance runoff capture and to direct water to a treatment or storage facility. Robbins (1980) presents examples of various grading treatments to control water infiltration and provide for mine water pollution control. In his study, reclamation of surface mines involving infiltration control reduced pollution by almost 100 percent.

Revegetation also can be effective in reducing the net percolation of surface water. Interception and evapotranspiration by the vegetation limit the amount of water available for deep percolation.

Containment by Liners. Where bedrock is fractured or too permeable to prevent tailings leachate from degrading ground and surface waters, the bottom and sides of a site can be "lined." Liners are usually composed of clay or synthetic polymers. Although asphalt or concrete liners have been used in the past, the problems of cracking of such rigid liners make them undesirable.

The design characteristics and use of liners in waste disposal are guided by the State Water Resources Control Board and Regional Water Quality Control Boards, and/or the Department of Health Services (where hazardous waste is involved). Thus, reclamation planning to assure long-term water quality protection should be made in conjunction with these appropriate agencies. Regulations in the State Water Code specify minimum standards for liners (Water Code, Title 23).

The type and characteristics of an approved liner will be dependent on the type of waste to be disposed. Various wastes or types of waste placement have a deletorious effect on the effectiveness of many liners. Estimation of the long-term effectiveness of these liners is, consequently, dependent on a knowledge of the type of wastes to be disposed of and the proposed method of disposal.

Synthetic liners: Synthetic liners are being increasingly used in mining operations. They are frequently employed in cyanide heap leach processing operations and at surface mines that do not have sufficient clay deposits at or near the site. When functioning properly, these liners can provide minimum permeability and maximum leachate containment. However, long-term water quality difficulties have been encountered in reclamation due to manufacturing problems, improper installation or ripping of these liners. General problems have been: (1) manufacturing

defects, such as pinholes; (2) inadequately prepared subgrade, leading to tearing of liners by rocks and debris; (3) tearing of the liner as it is unfolded or unrolled; (4) faulty seam sealing; (5) ripping of the in-place liner by heavy equipment in the placement of the tailings; and (6) deterioration of the synthetic material. Selection of sufficiently thick synthetic lining material (minimum of 40 millimeter thickness) and careful monitoring of manufacturing and installation can alleviate many of these potential problems, thus providing an effective reclamation technique.

Clay liners: Clay liners, often economically preferable when suitable clay materials can be found on the site or at a nearby location, can be less expensive than plastic liners and equally or more effective. By nature, clay liners are also less susceptible to many of the problems encountered in the use of plastic liners. Where heavy metals concentration is expected to be of concern in the leachate, clay liners can be particularly useful in that clays have sorptive properties, which can result in the binding of heavy metals to the clay particles.

Unlike many plastic liners, clay liners are relatively easy to install, and use established construction techniques and commonly accessible equipment. The clay must be spread and compacted evenly, but there are no problems with seams and holes. However, clay liners can dry out, which will increase permeability. In addition, clay liners can react adversely to certain types of waste placed upon them. Various wastes can alter the structure of the clay particles, causing them to be significantly more porous and permeable. This alteration of the clay structure can create a clay liner that is more permeable than some sand material.

Composite liners: Composite liners, which consist of a synthetic liner immediately underlain by a clay liner, combine the best attributes of both materials. The double layer acts as insurance against failure of either one. Lining materials must be tested for suitability to the specific waste materials they are to contain. The Water Code contains a suggested method to evaluate liner-leachate compatibility.

TABLE 1. Reclamation techniques for sulphide waste (Adapted from Deely, 1977).

Type	Descriptian
Drainage Diversion	Channeling of surface waters or mine waters to control volume, direction, and cantact time.
Impoundment	Physical restrictian of waters within an isolated area of an underground or surface mine.
Refuse Pile Reclamation	Burial or covering and revegetation of the discarded waste rock from mining.
Revegetation	Planting of grasses, legumes ar trees upon the surface or areas disturbed or altered by excavation or dumping during mining.
Inert Gas Blanket	Placement and retention within an underground mine of a gas that is not reactive in the acid mine drainage-forming pracess.
Microbiologic Iron and Sulphate Removal	Use af living organisms ta actively reduce acid mine drainage cantaminants.
Sterilization	Use of toxic materials to destroy ar retard living organisms active in the acid mine drainage forming process.
Micrabialagical Control	Use af living organisms against each other to retard the action of those which are active in the acid mine drainage forming pracess.
Neutralizatian	Pracess af chemically counteracting the polluting effects of acid mine drainage.
Flash Distillation	Rapid evaporation af acid mine drainage and the reliquefication of the remaining fluid, free of residual contaminants.
Reverse Osmosis	Passage through a selective membrane of the liquid portion of acid mine drainage thereby freeing it fram a majar partion of the residual contaminants.
Ian Exchange	Passage of acid mine drainage among reactive particles that selectively retain residual contaminants while the remaining liquid passes through.
Desulphating	Use of living organisms that thrive an metabolic pracesses that destray sulphate, which is a major residual cantaminant of mine drainage.
Sulphide Iran Removal	Precipitatian of iran fram acid mine drainage with the addition of selectively reactive sulphide campaunds.
Electrodialysis	Passage of acid mine drainage through an electrically-charged selective membrane allowing the passage of liquid, thus freeing it from residual contaminants with the appropriate electrical resistance ta passage.
Permanganate Iron Removal	Precipitation of iron fram acid mine drainage with the addition of an agent that axidizes the iron.
Regulated Pumping	Discharge of acid mine drainage at volumes, rates, times and locations sa that the contaminating effects will be minimized.
Stream Flaw Regulation	Cantainment and release of stream waters at valumes, rates, times and locations so that the contaminating effect will be minimized.
Deep Well Injectian	Placement of acid mine drainage ar its altered praduct into the subsurface through a vertical drilled hole.

Treatment Process. As shown on Table 1, there are a number of physical reclamation treatments available to reduce or minimize acid mine drainage: drainage diversion, impoundment, grouting, internal sealing, waste removal, pumping, etc. (Deeley, 1977). Isolation of the material from the atmosphere reduces the oxygen supply rate. Burial of the acid-producing material slows down the rate at which oxygen can combine with the sulphides. Burial of the material below the water table is even more effective because the diffusion coefficient of O_2 in water is about four orders of magnitude less than in air (Pionke and Rogowski, 1982).

Example Contaminant Control Approaches

Several current reclamation proposals for both active and inactive mines in California are available to illustrate the type of reclamation treatments being applied to existing water quality problems in different types of ore bodies.

Iron Mountain Mine in the Shasta Mining District is currently a Federal Superfund site. Specific treatments to minimize the historical water quality problems associated with the mine are being implemented by the U.S. Environmental Protection Agency. The copper, zinc, gold ore bodies and associated sulphide mineralization are in an area of California that receives over 60 inches of rain per year. Infiltration of the precipitation into existing waste rock, tailings, pits and tunnels has resulted in a mine water discharge from the site that is acidic and contains a heavy metal concentration (copper, zinc, cadmium, iron, lead, arsenic and aluminum) which may be toxic to fish. Possible solutions to this situation include: (1) storage and diversion of discharge waters; (2) source control (including isolation of waste rock and tailings pits, infiltration reduction, etc.); and (3) physical and chemical water quality treatment.

Leviathan Mine in eastern California (Alpine County) is an example where sulphur and pyrite materials (ore, overburden, waste rock and tailings) created an acid mine drainage and related heavy metal situation. Reclamation of the abandoned sulphur mine, under the direction of the Lahontan Regional Water Quality Control Board, was aimed at the control of acid mine drainage through landshaping, revegetation and water management.

Drainage from the overburden, surface and subsurface sulphur ore body has been measured as low as pH 1.3 (California Regional Water Quality Control Board, Lahontan Region 1970), and has caused aquatic and wildlife habitat degradation far down the Carson River drainage. Mass movement of old waste dumps has led to a continuous source of stream sediment and exposure of unweathered sulphide material.

The site has been reshaped to isolate the main areas of acid production and to stabilize the landslides supplying sediment to the area drainages. Revegetation has been initiated to reduce the amount of percolation and subsequent leaching of acid and heavy metals. Runoff is being diverted away from areas of greatest acid/heavy metal drainage and slope instability. After diversion, runoff is contained for evaporation/treatment and control. As reclamation was not introduced until after abandonment and recognition of a major water quality problem, this reclamation operation has been extremely costly. The types of reclamation treatments used at Leviathan, however, offer some sound approaches to situations involving potential contamination from producing overburden and waste rock.

DEWATERING WASH AND PROCESSING WATER

Dewatering is the removal of groundwater to keep the water table below the operation level of the mining site. Normally, it is only needed during the mining operation and does not directly affect the reclamation plan. The disposal of the water may affect the design of containment facilities that become part of the reclamation consideration. Also, if the quality of the dewatered aquifer is poorer than the quality in the disposal area, then the water must be treated as a wastewater, analogous to wash and processing water.

The qualities and amounts of wash water and processing water will, of course, depend on the type and size of the mining operation proposed. Sand and gravel operations, discussed in detail in the next chapter, generally produce large quantities of wash water and its related contaminant, fine sediment.

Reclamation planning for the disposal of these wastes requires an estimate of both quantity and quality. Often, especially in the case of sand and gravel operations, the disposal of sediment-laden, but otherwise "clean" wash water, can be handled through properly designed settling ponds. Wastewater containing other substances, such as minerals or large amounts of dissolved substances that could degrade surface water or groundwater, may require more elaborate disposal treatment. Specific requirements for the disposal of wash and processing waters are set by the California Regional Water Quality Control Boards. The appropriate Regional Board should be contacted during the reclamation planning process for advice on suitable disposal measures.

Depending on the anticipated quality of the processing water and the other needs of the operation, processing water can be treated, recycled and/or evaporated. Treatment, of course, will depend on the nature of the effluent, and its intended use and disposal method.

A variety of water quality treatments have been developed for most mining waste problems. Treatment of wastewater and materials before disposal may open up disposal options and limit more expensive reclamation solutions. Chemical treatments of mining waste may range from a simple flocculating agent to induce settling in a siltation pond to a full-fledged water treatment "plant." Potential treatments are specific to each type of mining process, the site of the operation and regulatory restrictions. Discussion of treatment methods is beyond the scope of this report. An engineer should be consulted if treatment is needed.

The wash and processing water generally will require some kind of temporary containment. The discussions of dams and pits later in this chapter should be consulted in such cases. If waters do not contain unwanted contaminants or sediment, they may be combined with other water from site drainage, if compatible with the specific Regional Water Quality Control Board requirements.

STORAGE AND HANDLING OF PROCESSING CHEMICALS AND BY-PRODUCTS

Surface mining operations will often have excess processing substances to be disposed of or recycled at the close of operations. Depending on the operation, these substances may span the range of entirely harmless to hazardous materials. In many cases, these substances may be removed for use at other operations or resold. Options for on-site disposal will depend on the concentrations and quantities of the substances and type of disposal site available. Many references are available to describe various processing and treatment techniques. The reclamation plan should clearly state what will be done with these materials, in order to avoid any confusion as to the means of disposal. Again, as the disposal of many processing materials and chemicals are regulated by the California Department of Health Services and the California Regional Water Quality Control boards, these agencies should be contacted in the reclamation planning process to determine appropriate disposal techniques.

The handling and storage of processing chemicals on the mining site may create the potential for spills of contaminants. This is primarily an operating issue, but if the disposal of soil or water contaminated by a spill is on the site, it may affect the reclamation and subsequent use of the site.

INTEGRATION OF WASTE DISPOSAL SITE SELECTION, PROCESSING AND DISPOSAL METHODS IN RECLAMATION PLANNING

Integrated operational and reclamational planning can maximize both profit and long-term water quality. Evaluation of several potential processing methods, disposal sites and disposal methods can lead to the optimum combination of techniques. A change or addition in the processing method may increase the expense of processing, but decrease overall disposal amounts and total reclamation costs. Initial estimates of the quality of leachate, wastewater or processing by-products should be made before the disposal site or method is selected. If no water quality problems are anticipated, selection of a disposal site may be only a matter of appropriate storage space, long-term erosion control and the selection of a suitable end use. If, however, leachate or runoff is estimated to be detrimental to water quality, an adjustment to the processing method should be evaluated, and a site or sites capable of storing the water in isolation from surface waters and groundwaters should be identified or created. This may mean adding a waste treatment loop to the processing system, transporting waste to an already established disposal site, finding a naturally "tight" or hydrologically sealed area or creating a waste containment facility.

Reclamation Measures to Protect Hydrologic Processes on the Mining Site

Mining operations can change surface water and groundwater processes. Such changes affect erosion, water supply yields from watershed and the potential for flooding. These effects often are caused by the removal of overburden and vegetation and by the re-routing of surface water runoff. Other mining operation effects, such as changing local groundwater levels, are discussed in the next chapter on sand and gravel mining.

When changes are made to the hydrologic system, the results cannot always be predicted very precisely. Thus, a basic approach to site reclamation is to mimic the original conditions of slope, vegetation, etc., as closely as possible. There are hydrologic methods, such as the SCS Methods discussed in Chapter 5, to predict runoff based on watershed characteristics. These can be used to estimate effects of the proposed mining operations and reclamation measures. Most of the methods, however, are empirical — that is, having coefficients derived from observations of actual watersheds. Typically, there are not coefficients for the exact conditions resulting from the mining and reclamation. The methods can then only give a partial indication of probable effects. Overton and Meadows (1976) give examples of the use of some sophisticated hydrologic models to predict runoff alterations from strip mining, logging and urbanization. If an analysis based on simpler methods suggests major change in runoff may occur, then a study using the more complex models may be needed. These models should be used by persons with considerable hydrologic expertise.

Where the site changes are modest, the effects can usually be minimized by controlling runoff on and around the site, combined when necessary with containment by damming or in pits.

RUNOFF CONTROL TO MITIGATE EROSION AND LEACHATE PROBLEMS

On-site runoff control serves two essential functions as a reclamation technique. First, capture and channeling of surface runoff can reduce the amount of site erosion. Erosion of a fill, tailings dam or waste cap, for instance, may cause failure or exposure of a waste disposal site; this would leave waste open to transport by subsequent wind or water erosion. Uncontrolled erosion of topsoil at a reclaimed site may also destroy revegetation efforts. Second, leachate production is directly influenced by the amount of water available for percolation through the waste. If only a small amount of water is available to go onto the disposal surface, only a small amount will be able to leach through the waste. Diversion of surface runoff away from the disposal site will limit the quantity of water available for percolation.

Diversion of surface water is commonly accomplished by using a system of interception ditches. These ditches, encircling the disposal area, can be used to capture runoff coming from surrounding areas and direct it away from or around the site. This water can then be either discharged directly to a drainage channel or contained in a settling basin for removal of sediment, and then later released.

If direct diversion to a drainage channel is used as a reclamation technique, caution should be used to insure that the diverted runoff, concentrated by this process, is released in a non-erosive manner. Channelized and concentrated surface runoff will often have a far greater erosive capacity than naturally dispersed runoff. Velocity dissipators or channel reinforcement may be needed to slow the runoff water and reduce its erosive ability.

Long-term maintenance of these diversions is often necessary to insure success of the reclamation plan. Sediment, carried by surface runoff, is commonly deposited in the drainage control

system. If this sediment is not routinely removed from diversion channels or settling basins, the amount of surface runoff water the system can handle will be reduced.

WASTE CONTAINMENT BY DAMMING

When the runoff quantity is large or when sediment and turbidity are present, it may be necessary to contain the runoff temporarily by a dam. Dams are also used in many larger mining projects to contain tailings and waste water. Proper design and construction of these dams are critical to the control of long-term water quality and overall stability of the mined site. Sediment tailings dams must store solids permanently and retain water temporarily over the life of the project. Design of these features for long-term stability usually requires information pertaining to physical properties of the tailings themselves, stability of subsurface materials, type and history of precipitation events, seismicity and groundwater. Especially important is the control of seepage. If not adequately considered during the planning and design stages, seepage may become a long-term maintenance and reclamation issue. Adequate seepage control is required to: (1) prevent water from eroding through the dam (this led to the failure of the Teton Dam in Wyoming); (2) conserve water that can be recycled for processing; and (3) minimize and control possible degradation of ground and surface water systems (Guerra, 1979).

Many standard engineering techniques are available to accomplish the necessary seepage control and to design a dam with long-term stability. General references, such as Soderberg and Bush (1977), provide an overview of these techniques. A professional engineer, however, should be consulted for specific design considerations. If the dam is 25 feet high or stores more than 50 acre-feet of water, the Department of Water Resources, Division of Safety of Dams will be involved for dam safety. Storing water may require a water right permit from the Water Resources Control Board, Division of Water Rights.

CONTAINMENT BY IN-PIT STORAGE

An alternative to containment in a designed surface impoundment is placement of wastes in an excavated pit, usually one excavated as part of the mining activity. In-pit storage reduces the need for acquisition of additional land, minimizes potential tailings erosion, eliminates the need for dam design and construction and reduces the hazard of a large open pit. Where groundwater has been exposed by mining, in-pit disposal may also serve to reduce or eliminate decreased water quality effects caused by evaporation (more discussion of this is presented in the next chapter).

Selection of pit sites for disposal will depend, to a large extent, on the anticipated leachate qualities, the hydrogeologic characteristics of the pit walls and bottom and the groundwater regime. Where leachate is not expected to be detrimental or where the pit appears to present a hydrogeologically "dry and tight" area, in-pit disposal may be a far more desirable reclamation measure than the construction of a separate waste disposal site.

CONTROL STRUCTURES TO MITIGATE EROSION AND SEDIMENTATION

Many of these procedures to contain flows to reduce leachate generation will also help reduce erosion. Erosion may also be a problem even in the absence of leachate problems. Some specific measures to manage erosion and sedimentation are discussed in Amimoto (1977), Law (1984), and Whipple and others (1983).

REVEGETATION

Revegetation usually is an essential element of the protection of hydrologic processes on a watershed. The vegetation protects the land surface from erosion by blocking the direct impact of raindrops, by binding the soil in the root system and by slowing the velocity of water flow across the surface. Grassed channels may serve in place of more costly lined channels for part of the site drainage system. Plants that use large amounts of water may reduce the water available to create leachate.

The primary hydrologic aim of revegetation usually is erosion control. Success depends on proper preparation of the land to receive and protect the seeds or seedlings until they become established, the choice of plants that will grow quickly and persist after they are established, the seedling and mulching procedures and the watering and fertilization procedures. A separate report published by the Division of Mines and Geology provides guidance on revegetation (VanKekerix and Kay, 1986). A pamphlet by the California Association of Resource Conservation Districts (1986) reviews and summarizes the concepts of revegetation and provides planting recommendations for some plants that have been successful in erosion control efforts. The pamphlet applies to areas having the "mediterranean climate," which includes most of California west of the Sierras.

Erosion control must start during the project operation to prevent problems from becoming too large to reclaim. The reclamation plan should address the long-term endurance of measures started during both operation and reclamation phases. The reclamation aspect requires the additional consideration of the relation of revegetation to proposed end uses.

CHAPTER 4. WATER-RELATED RECLAMATION ISSUES ASSOCIATED WITH SAND AND GRAVEL MINING

Hillside and Pit Mining

Sand and gravel mining in California occurs primarily in active stream deposits or in ancient sedimentary deposits formed by alluvial fans, historic streams and marine processes. Reclamation of those surface mining operations that are occurring in active stream or drainage channels (and those that might be in temporarily inactive channels) is discussed in a later section on in-stream mining. Those operations that take place on elevated stream terraces, isolated from natural floodflow, and in pits removed from stream channels are discussed here.

Reclamation of non-in-stream, or terrace and pit and sand and gravel operations is largely dependent on the proposed end use(s). Unlike in-stream mining, there are a variety of end uses applicable to these operations, such as: runoff storage; groundwater recharge enhancement (water spreading); water-based recreation; wildlife habitat; residential lake development; and building sites.

Primary considerations for many of these potential end uses are the quality, elevation and seasonal fluctuation of the groundwater table. Those operations that leave surfaces below the level of the water table will have substantially different options and issues to consider than those which do not. Thus, an important initial stage of reclamation planning is the determination of the site's groundwater elevation, its potential seasonal range and general hydrogeologic characteristics.

Cores, borings, trenches and historic site information evaluated in the exploration stage of the project can often yield at least a preliminary indication of the site's hydrogeologic conditions. Delineation of the final pit surface relative to the highest groundwater level, however, usually requires a more extensive search for information or a long-term, coordinated, data collection program.

Sand and gravel site end uses can be more easily designed if the highest elevation of the groundwater table is significantly above or below the projected final surface of the proposed operations. Where the highest groundwater elevation is estimated to be "near" the proposed final surface, reclamation may be difficult. Fluctuation in a near-surface water table may produce marshes or swamps instead of grazing fields or mud puddles rather than recreational lakes.

Revegetation, grading and erosion control programs are also dependent on the accurate estimation of the groundwater conditions at the reclaimed site. Slope stability studies, vegetation selection and the design of surface water control, all require some sort of hydrogeologic information. Thus, determination of basic groundwater characteristics should be a primary goal of reclamation planning for most sand and gravel terrace or pit mines.

An example of an operation and reclamation plan that relies heavily on accurate groundwater data is Teichert Aggregate Company's Martis Valley sand and gravel mining operation near Truckee, California. Teichert proposes to mine sand and gravel from a glacial deposit down to an elevation 14 feet above groundwater, leaving the site in a condition suitable for grazing and regional wastewater treatment. Maximization of extraction from the deposit will depend on the accuracy of Teichert's predicted groundwater levels at the site. Too low a predicted groundwater elevation will make revegetation for a successful end use difficult; too high will result in a loss in potential product. An additional factor in the development and selection of a final reclamation surface is the existence of the Tahoe-Truckee Sanitation Agency (TTSA) on the adjoining property. TTSA currently injects treated municipal wastewater into the gravel deposit, elevating existing (pre-TTSA) groundwater levels in the area. Future TTSA projections of increased injections rely on the existence of a specific volume of the sand and gravel, some of which lies in the area of Teichert's lease. Teichert and neighboring TTSA are thus working together to ensure that the operation provides a final reclaimed surface suitable for both grazing and use as a wastewater injection field.

RECLAMATION ISSUES FOR "DRY" OPERATIONS

Sand and gravel operations entirely above the water table often present the least reclamation difficulties from a hydrologic viewpoint. The material is easily excavated and recontoured to allow numerous subsequent end uses. Heavy metals discharge and acid drainage, discussed previously, are rare water quality problems for these types of operation. Of greatest hydrologic concern in reclamation are potential siltation and turbidity that can result from site runoff or the release of wash waters.

Silt and turbidity may be caused by erosion due to the drainage water diverted around the mining site or by the runoff from the mining site. The diverted drainage has a greater erosive power because it has been concentrated in a channel. The methods to reduce erosion impacts are not unique to mining sites. The methods in the Department of Conservation's "Erosion and Sediment Control Handbook" (Amimoto, 1977), for example, can be applied. The runoff from the mining site generally must be contained in a pond to eliminate suspended sediments and reduce the turbidity before being released. If no deletorious materials are contained in the wash waters, they may be combined with the general site runoff.

The Regional Water Quality Control Boards should be contacted regarding the siting and design of the ponds or any other waste management facilities. The requirements in the State Water Code (Title 23, Subchapter 15, Article 7) apply to mining wastes. The Regional Boards or the State Water Resources Control Board can provide information on the requirements, which includes flood protection, drainage criteria and construction standards.

OPERATIONS BELOW THE SEASONAL HIGH WATER TABLE

Common end uses for sand and gravel pits excavated below the water table include recreational or residential lake developments, wildlife habitat, runoff storage and groundwater recharge enhancement (water spreading). To a large extent, the selection of these end uses is determined by the existing groundwater characteristics and the type of long-term management foreseen by the reclamation planner, or local agency with land-use planning jurisdiction. Often, more than one use is proposed for the same operation. Many uses can be compatible, such as wildlife

habitat and flood control or recreation and groundwater spreading.

The following is a discussion of some of the common hydrologic issues associated with these reclamation end uses, their data needs and potential means of analysis.

Recreational/Residential Lakes

Development of recreational or residential lakes is one of the more popular and profitable end-use selections. Close proximity of most sand and gravel sites to urban areas makes this an attractive option. The same growth that is being supplied building materials by the sand and gravel industry often creates the demand for recreational use of the mining site.

Hydrologic considerations in the development of this type of end use usually include: potential lake level (or groundwater) fluctuation; reduction in groundwater recharge; and reduced water quality due to eutrophication, sedimentation, contamination and evaporation.

Potential Water Level Fluctuation: Rapidly or widely fluctuating water levels can be a problem in either recreational or residential lakes. Shorelines, sloped shallowly for access, may expose unsightly mud deposits if lake level is lowered. Conversely, significant groundwater rise, heavy rainfall or runoff can cause flooding of near shore areas. If this occurs, docks, moorings, and other recreational facilities must be moved back and forth and flood protection devices have to be installed (Rickert and Spieker, 1971).

To avoid these situations, reclamation planning should determine the elevation and range of groundwater levels at the proposed site. Properly designed final shore configuration and location of facilities or housing can then be determined. If groundwater levels vary substantially, season to season, or year to year, it may be necessary to coordinate or supplement management of the lake with local surface water flows.

Evaporation: Exposure of groundwater can cause a decrease in water quality due to evaporation. Evaporation from the water surface concentrates natural dissolved solids. High levels of total dissolved solids (TDS) are not desirable and limits have been set for some water uses based on TDS (see Department of Health Services and Water Resources Control Board regulations and policies). In areas of high evaporation and/or low rainfall, large scale exposure of regional groundwater may not be desirable. The reclamation planner may wish to consider a reduced depth of extraction to a level above the water table, a final pit configuration minimizing exposed water surface area or an alternate end use involving backfilling.

Eutrophication: Eutrophication is a natural aging process of lakes. Aquatic plants become abundant, decreasing the available oxygen in the lake water. If the eutrophication process goes to completion, the result is an oxygen-depleted lake, choked with vegetation. This process is speeded up by the addition of organic matter, nitrogen and phosphorous found in septic tank leachate and agricultural and urban runoff.

If residential or recreational use is planned, reclamation should consider potential means of reducing eutrophication. Grading can channel runoff from home sites or facilities away from the lake. Any revegetation program should minimize fertilization near the lake shores and time application of fertilizers so that nitrogen rich runoff will be unlikely. Also, when planning surrounding development, municipal sewer systems are preferable to septic tanks which, given a near-surface water table provided by a lake, might be likely to fail.

Potential Contamination: Direct contamination of an aquifer is a hazard where any groundwater is exposed. Hazardous or toxic substances spilled into the lake can directly enter the aquifer. No surface material is available to filter contamination, or reduce the speed of its migration into the aquifer. The rate of potential regional contamination is a function of the permeability of the sides and bottom of the pit.

If potential contamination of an aquifer is a concern, reclamation planning could include access restrictions such as fencing, prohibition of public swimming, boating, etc. Alternative water sources could also be developed as a contingency plan, if domestic, agricultural, industrial, use, etc., might be threatened.

Reduction in Groundwater Recharge: Extraction of the sand and gravel from an aquifer allows more water to be held in the pit space than was possible before extraction. Water that was previously held in the pores between sand and gravel grains is now free to fill the entire volume.

Water in an excavated pit may be supplied by water from a local acquifer, surface runoff or direct rainfall. If the water level produced by these combined processes is higher than water levels in aquifers intersected by the pit, and permeable material exists between the two, water will move from the pit into the aquifer(s).

Blocking of this water movement by siltation, however, is common. Over time, the sides of the pit will erode and surface runoff from surrounding areas will carry fine sediments into the pit lake. This then results in less water moving into the aquifer. This erosion and runoff can be minimized with proper grading and revegetation, but may still, with time, deposit a layer of fine silt and clay that will decrease the transmission of water from the lake to the surrounding aquifer.

Water Spreading and Runoff Control

Water spreading or runoff storage facilities are frequently desirable end uses for sand and gravel pits. They can be economic to the mining company and serve a public need. Many operations, particularly in central and southern California, may find the community more receptive to a proposed operation if reclamation involves this sort of end use.

Planning of these end uses usually involves the cooperation of several entities. The Regional Water Quality Control Board, State Water Resources Control Board (Division of Water Rights), Department of Water Resources, county or city planning agencies and local water and flood control districts are frequently key players in the reclamation planning stages. Often their approval is required for both the general concept and the proposed long-term maintenance of the end use. Reclamation issues that are frequently involved in this type of end use include: water quality degradation due to evaporation, sediment, or contamination and maintenance of groundwater recharge rates.

Sediment Control: Surface runoff, diverted to the site for storage or recharge, usually carries a sediment load. This sediment will "fall out" and be deposited as it enters a pit because the velocity of the water is slowed and it can no longer transport its sediment load.

If the pit is intended for runoff control, the sediment that fills the pit may limit the amount of water that can be stored during any given flood event or winter season. If the pit is designed for water spreading, the sediment that coats the bottom and sides of the pit will limit the rate of recharge from the pit to the underlying material. In either case, the incoming volume of sediment must be estimated and controlled or removed.

Basically, the kind of analysis necessary for design of control structures or estimation of maintenance costs, relies on historical flow and sediment transport data. This information, coupled with the proposed pit configuration and water management scheme, should be sufficient to allow an estimation of both the volume and location of sediment deposition. More detailed information on sediment-load estimation will be presented in the following section on in-stream mining.

It is often desirable to remove most of the sediment before the inflowing water enters the pit or recharge pond. A series of smaller upstream pits or check dams can be designed to accomplish this. With sediment concentrated in a smaller, and often more accessible area, long-term maintenance costs can be reduced. Cleaning out the reservoirs or ponds can be accomplished during the dry season or between flood events, and can be carried out without specialized equipment.

Long-term dredging of material deposited in the excavation requires, of course, specialized dredging equipment and may not be desirable if the pit is being used for other purposes. Recreation or wildlife habitat use may not be consistent with an ongoing dredging program (Krenkel and others, 1976).

Dredging may also pose water quality problems. Contaminants can be transported by sediment. When agitated by dredging, these contaminants can prove to be more detrimental to the quality of the water than associated turbidity Thus, potential sediment-contaminant quality problems should be analyzed before a long-term program of dredging is proposed as part of the reclamation plan.

Wildlife Habitat/Open Space

This type of reclamation end use frequently requires a minimum of management. Pits, with or without year-round water, can be used to supplement diminishing wildlife habitat and provide open space. In urbanizing areas, open space is frequently rare and can be of substantial benefit to the community. Exposed water surfaces can be attractive to a variety of waterfowl and riparian organisms that might not otherwise be preserved in the area.

Exposed water surfaces, however, are subject to evaporation, contamination potential and sedimentation, such as that discussed above. If the groundwater exposed by extraction is of high quality and/or is currently sustaining several beneficial uses, long-term management of the resource area should be included in the reclamation plan.

In-Stream Sand and Gravel Mining

Stream systems are in a state of dynamic equilibrium. Therefore, changes by mining to existing hydrologic components, such as the stream's sediment yield, width, depth, etc., will necessitate hydrologic changes to rebalance the system. These adjustments by the stream system are most noticeable in the form of altered rates and locations of flooding, erosion and sedimentation. A primary objective of SMARA, therefore, is the rehabilitation of streambeds and streambanks to a condition minimizing erosion, sedimentation and flooding (SMARA Sections 2733, 2772). The potential direct impacts on the stream make it more likely that permits will be needed from water regulatory agencies such as the Water Quality Control Boards and the U.S. Army Corps of Engineers.

While this concern applies to all mined lands and their drainages, it is particularly important to the reclamation of in-stream mining operations. These operations directly alter the stream's geomorphology (shape, size, etc.), channel capacity and sediment load. The reaction of the stream system to these in-stream modifications can vary quite significantly depending on the amount of material extracted, the location and depth of the extraction, and the watershed characteristics.

Much of the success of reclamation treatments proposed for in-stream mining depends on the data available to evaluate existing and proposed conditions. The type of data necessary includes both site-specific information, such as cross sections, longitudinal profiles and erosion surveys, and watershed data, such as seasonal flow rates and volumes, sediment replenishment rate and basic stream geomorphology.

Historically, the type of watershed data necessary for a complete evaluation of both in-stream sand and gravel extraction and reclamation has been lacking. In the last 20 or 30 years, however, more attention has been directed at stream and watershed processes.

PROBLEMS AND POSITIVE HYDROLOGIC EFFECTS OF IN-STREAM MINING

In the last three decades, a significant amount of research has been done on stream systems. Classic studies such as those of Leopold and Maddock (1953), Schumm (1960, 1961), Bagnold (1966), and Maddock (1969), have documented the complex interaction of hydrologic and sedimentologic factors that result in a "stream." Channel shape, width, depth, roughness (or resistance to flow) and stability are now known to relate to a number of variables: water discharge, sediment discharge, channel slope, sediment size and velocity of flow. An alteration of one of these factors may cause a change in others.

Reactions of various California stream systems to both individual and cumulative in-stream extractions have been studied by a number of researchers. These studies have resulted in the recognition of problems as well as positive effects of in-stream sand and gravel extraction. These include:

1. Degradation (erosion) of the streambed and banks
2. Reduction in sand and gravel supplies to downstream operations, river channel and beaches
3. Degradation of aquatic/riparian habitat

4. Contamination by sediment, gasoline oil and/or other waste products
5. Reduction of groundwater recharge and/or storage
6. Potential increased flood flow capacity
7. Potential restoration of previously impacted fishery habitat

Many of the adverse effects can occur both on- and off-site. Changes in stream base level, for instance, both up and downstream, necessitate reclamation treatments over a larger area than just that of the extraction site. Thus, before data and design needs can be assessed, the reclamation planner must be aware of the processes involved and the possibilities for reclamation.

The effects listed above can be grouped and are discussed below in major categories: (1) changes in water flow and storage, and (2) stream erosion and sediment yield effects, plus various other effects that are less common or less significant from the hydrologic viewpoint. This does not mean the latter effects are never important. For some projects, they may be crucial to the overall decision. But for the review of hydrologic issues, they will be of less central interest.

Changes in Water Flaws and Storage

In-stream sand and gravel removal has a direct effect on the flow of water in the stream channel. The channel may be both deepened and widened, creating a larger area for the flow of water. Vegetation and other flow obstructions on the adjacent floodplain may be removed in the mining operation. On the other hand, the normal low-flow channel may be re-routed, and new obstacles, such as tailing piles and access roads, may be located in the floodplain area.

Flood Flows and Potential Flood Control Benefits. The most significant concern in flood flow situations is usually the effect during high flood flow conditions. The potential flow capacity is usually increased, but actual flood effects may depend on the conditions upstream and downstream from the site. If the mined area is very long in the direction of the stream flow, the end effects (from upstream and downstream) may be small and the channel may carry flood flows with lower water surface levels than previously over most of the area. If the stream channel above and below the mined site has less capacity, the flow must make adjustments as it enters and leaves the mined segment. If the mined segment is short, the flow may be controlled more by the lower capacity segments. In this case, the larger area of the mined site can act on the flow as a pond, with a higher water surface level than existed before. Thus, if the change in cross section area will be large — for example, doubled — and might persist for several years, a hydraulic analysis should be performed. The analysis methods need not be complex. The discussion in Chapter 5 mentions the flow concepts of the energy equation and the Manning equation that are used. However, because the application of these methods is relatively complex, an explanation of this analysis is beyond the scope of this report.

If the volume of material mined is large and the area adjacent to the site is not a high flood risk area, the storage of flood flows in the mined area may reduce flood levels downstream. This effect is usually too small to be a significant feature for large floods, but it could help if flooding is a problem at the frequent, but lower volume flood flows.

The reclamation planner should note that where sediment replenishment is high, the flood control benefits of in-stream extraction may be short-term, unless extraction continues over a long period of time. High rates of sedimentation will eventually fill in the lower stream gradient area created by the extraction, and flooding frequency will return to pre-mining rates.

When planning for potential flood control benefits as a reclamation use, streambank and bed erosion control measures should also be considered. In-stream mining excavation increases the capacity of a stream channel and thus results in containment of greater quantities of floodwaters and higher velocity flows. Where the excavated channel ends, however, the downstream channel section may not be able to handle the increased delivery of flood water. In some situations, increased protection of one channel stretch may mean increased downstream flooding or erosion.

Groundwater Effects of In-Stream Mining. Groundwater levels, recharge and storage potential may be affected by in-stream sand and gravel mining. The impacts, however, are largely dependent on the relationship between the streams and the regional aquifers.

In some regions, there is little interaction between the stream and surrounding aquifers due to lack of: (1) streamflow; (2) permeable channel materials to promote recharge; or (3) an aquifer physically adjacent to the stream channel and banks. Many situations do exist, however, where surface streams contribute to the groundwater system or vice versa. Alteration of these systems may cause significant impacts to the local ground or surface water supplies.

Three examples of in-stream, mining-related conditions to consider in reclamation planning are as follows:

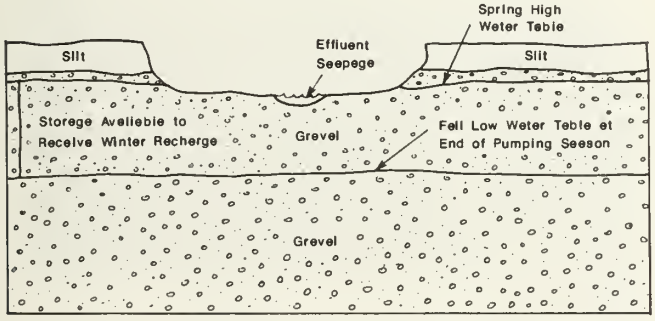
Example A: Siltation or deposition of fine-grained sediment can result from turbidity related to in-stream skimming, pitting or dredging. Deposition of this fine material on and in permeable gravels can limit the amount of infiltration from the stream into the regional aquifer. Reclamation treatments to preserve stream or groundwater levels usually involve limiting the deposition of homogeneous, widespread layers of silts and clays, or excavating them. This unwanted fine-grained material is often valuable as a topsoil medium for revegetation efforts on other portions of the mine site (for example, to re-establish disturbed riparian vegetation).

This is a potential concern: (1) when the natural stream has a sandy or gravelly bottom, not thickly covered with fine silt; (2) when the flood estimated to occur every year or two is not large enough to scour out the fine material; and (3) when a significant fraction of fine material is in the area to be mined. These conditions can usually be determined from the preliminary information collected at any potential in-stream mining site.

In many operations, a settling pond or ponds are used to control release of turbid water. If these facilities cover a large groundwater recharge area, it may be necessary to remove the deposited fine material. Where silt has reached and been deposited in the stream channel, however, it may be difficult to remove the material deposited in the stream channel without creating additional turbidity.

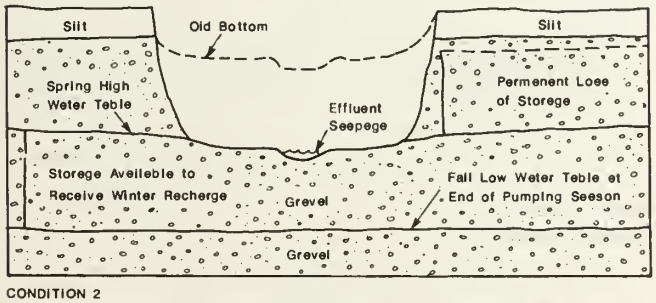
Example B: If sand and gravel of the streambed is permeable and hydrologically "connected to" a near-surface aquifer, as shown in Figure 4, the sand and gravel deposit may act as an important means of storing and percolating surface runoff to the aquifer. Removal of these gravels and/or subsequent lowering of the streambed may limit or totally eliminate contact between the stream and large portions of the aquifer at most stream flow levels. This would limit groundwater recharge to periods of large flood-flow events.

This condition might exist whether a stream is normally losing water to the aquifer or receiving water from it. After the bed of the stream has been lowered, the stream usually will only be receiving water from the aquifer. The preliminary data collected for the mining site should include delineation of the groundwater levels in the area. If the water table is above the lowest level to be excavated, a more detailed review can be conducted to determine whether the stream is "connected to" the aquifer. If surface and groundwater supplies are extensively used, this information may be readily available. It may also be developed during geophysical explorations, or if borings are made to moderate depths. If not, special sampling may be needed (Everett, 1983). If the water table will be intersected and the stream and aquifer are well connected, a more quantitative estimate of discharge or recharge relationships will be necessary. Although specific methods are beyond the scope of this report, delineation of important aquifer recharge areas would serve to identify those areas that require the most comprehensive reclamation treatment. If critical areas cannot be avoided due to limitations of the aggregate resource, infiltration or spreading basins can be used to compensate for recharge loss.



CONDITION 1

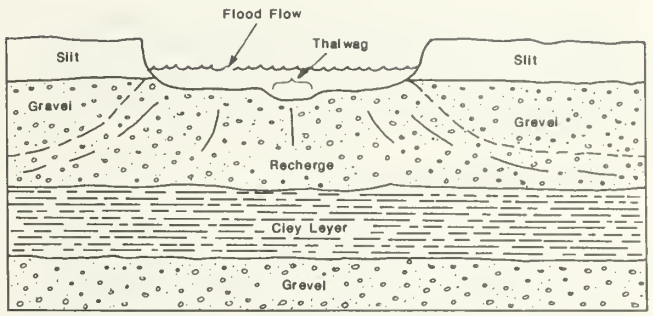
Spring water table is higher than the creek bed, which results in movement of groundwater into the creek channel to support surface flow. After the pumping season, the fall water table is below the creek bed, which provides available storage for recharge of winter flow.



CONDITION 2

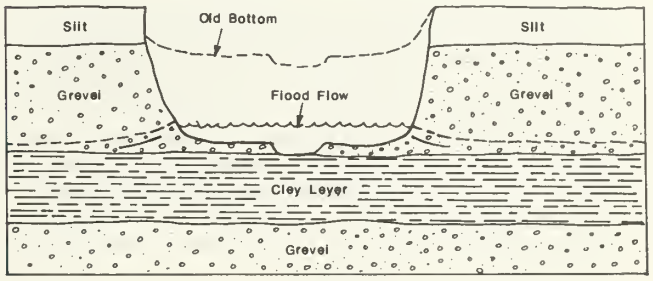
Creek bed has lowered to where spring high water table intercepts it at a lower elevation. Since the creek acts as a drain, it prevents the water table from rising to the Condition 1 spring water table position. The results in a permanent loss of storage equal to the amount of creek bed lowering.

Figure 4. *Influence of streambed lowering on recharge when a clay layer is present. From Woodward-Clyde Consultants, 1976, Aggregate extraction management study, County of Yolo, California: Prepared for the County of Yolo Planning Department, Aggregate Resources Management Committee, 128 p.*



CONDITION 1

Recharge opportunity is at a maximum because storage is available in the gravel below creek channel even though clay layer restricts vertical movement. When low flow is restricted to thalweg only, infiltration and thus recharge opportunity is unchanged.



CONDITION 2

Creek bed has lowered to where thalweg is in contact with top of clay layer. Recharge opportunity is greatly reduced and occurs primarily through creek banks. When low flow is restricted to thalweg only, infiltration and thus recharge essentially ceases because of clay layer.

Figure 5. *Influence of streambed lowering on loss of groundwater storage during spring high water table. From Woodward-Clyde Consultants, 1976, Aggregate extraction management study, County of Yolo, California: Prepared for the County of Yolo Planning Department, Aggregate Resources Management Committee, 128 p.*

Measures to control streambed lowering are presented in subsequent sections. If the stream gradient can be maintained through reclamation treatments, and sediment replenishment is relatively quick, the effect may be short-lived.

Example C: A third streambed-lowering situation is shown in Figure 5. High groundwater supplies water to the stream from the aquifer. The maximum aquifer level is controlled by the stream. With streambed lowering, the groundwater table is significantly higher than the stream and discharges greater quantities of groundwater into the stream. This results in a regional lowering of the water table to a level in balance with the new streambed elevation.

The lowering results in the loss of storage in the aquifer. Groundwater cannot be maintained at a higher level because flow into the stream drains the aquifer. This example is similar to Example B, and the same data and mitigation measures would apply here as well.

Stream Erosion and Sediment Yield

Just as it is important to leave a quarry site in a final configuration that will not create erosion problems, it is important to leave an in-stream sand and gravel excavation in a condition that will minimize scour and adverse sedimentation, both on-site and off. Four main aspects of in-stream site conditions should be considered in the assessment of reclamation treatments for this goal: channel slope; the erosional resistance of stream bank and bed material; channel alignment and flow direction; and stream sediment yield.

Sensitive Stream Conditions. Lowering of the streambed by sand and gravel extraction will cause a localized increase in longitudinal slope at the upstream end of the excavation. This will increase the velocity of the streamflow and the erosive sediment-carrying capacity of the stream's water. The higher erosive capacity may cause erosion of streambeds and/or banks at the upstream edge of the site. In many cases, the location of erosion is dictated by geology, stream channel shape or sediment type. If either the streambed material or the bank material is significantly more resistant, the stream will concentrate erosive power on the banks or the bed, respectively.

The erosion can progress upstream from the site itself. The upstream movement of an excavation's headcut is called the "migration of a knickpoint." This movement can be damaging

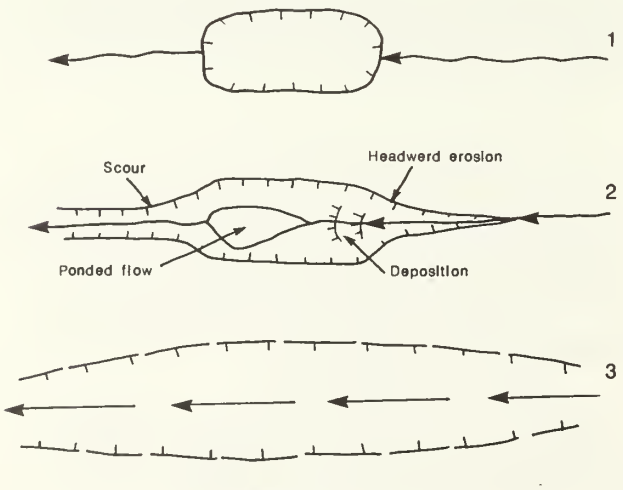


Figure 6. Headword erosian ond scaur resulting from single, deep pit in stream channel. *From Envicam Corporation, 1979, Santo Clara River, sand ond grovel extraction, Master EIR study, Finol Environmental Impact Repart: Prepored for Ventura County Resource Manogement Agency.*

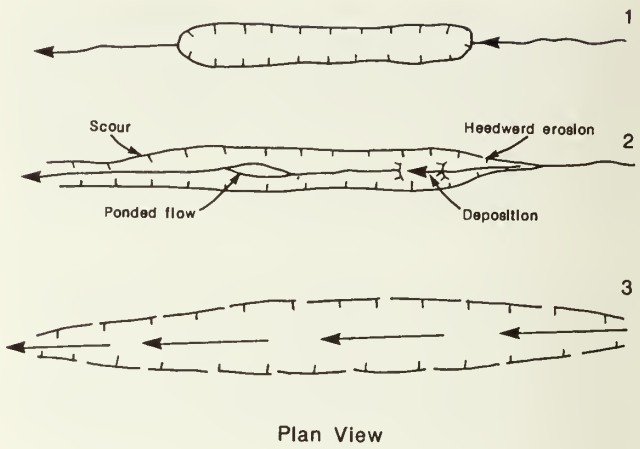


Figure 7. Headward erasion and scour resulting from single, linear, shollow pit in stream channel. *From Envicam Corporatian, 1979, Sonto Clara River, sond and grovel extractian, Moster EIR study, Final Environmental Impoct Report: Prepored far Venturo County Resource Management Agency.*

to the stability of a natural channel and any man-made structures associated with it. The effects of this type of gradient alteration have been particularly noticeable on bridgeworks, pipeline crossings and bank protection structures, where lowering of the streambed results in the undercutting of the structures. In some cases the knickpoint migration has affected structures several miles upstream. As was stated in Chapter 1, SMARA requires the lead agency receiving an application to notify the California Department of Transportation whenever mining activity is proposed within one mile upstream or downstream of any state highway bridge.

Higher erosive capacity in a region of extraction can also result from reduced sediment load. Removal of sand and gravel from a stream system decreases the sediment available for stream transport. Water that once used its energy to transport sediment has less sediment to carry, and thus it is below its capacity and has more energy to use as an erosive force.

Deep pits, left at the end of operations, will also act as sediment traps. The greater depth and subsequent lower velocity will cause sediment to drop out and begin to fill the pits. The water that flows out from the excavation area will have a reduced or "starved" sediment load. This water has a much greater capacity to erode in order to "get back" its lost sediment load to achieve equilibrium. This situation can lead to significant downstream erosion.

Depletion of sediment from the stream may also affect downstream mining interests by decreasing the replenishment to their site and/or eroding existing deposits.

Often, this sediment supply problem is not apparent until in-stream erosion actually starts. At that point, significant channel changes often occur, unique to each stream system (Gessler, 1971; Leopold and Langbein, 1962; and Yang, 1971). Estimations of the effect of sediment removal can be made by comparison of the rate of sediment withdrawal to the rate of

replenishment. Extraction rates that approach or exceed the replenishment rate can cause a situation where erosion is likely to occur. The extraction rate is stated in the mining application, but the replenishment rate must be estimated. As described in Chapter 5, methods for determining sediment transport and yield in streams are not well developed. Since most of the sediment transport can occur in the more rare, high flow floods, what seems to be excessive extraction for several years might actually be quite reasonable. If the proposed extraction rate exceeds the quantity replaced each year, a quantitative justification would be appropriate. The reclamation plan should also evaluate whether the mined material will be replenished before the high flows occur that can cause severe erosion damage. If not, protective measures should be included.

Reaction of a stream system to changes in slope, sediment load and flow direction will often depend on the relative resistance of stream bed and bank material. The most easily eroded material in the stream channel bears the brunt of the erosional damage (Lane, 1955; Little and Mayer, 1976; Schumm, 1960).

In the past 10 years, significant research has been focused on a natural mechanism for streambed protection from erosion. The mechanism is called armoring: the development of a relatively coarse streambed and bank cover that is resistant to low and intermediate flows (see, for example, Brown, 1975; Little and Mayer, 1976). Removal of this protective shield by in-stream mining has been found to lead to accelerated rates of erosion (Lagasse and others, 1980; California Department of Water Resources, 1984; Woodward-Clyde Consultants, 1980).

Additional stream erosion can also be caused by changes in the flow pattern or channel alignment during excavation. Excavation of the streambed and bank material, and improper final channel shaping can redirect the force of the stream's flow against erodible banks or foundations of structures.

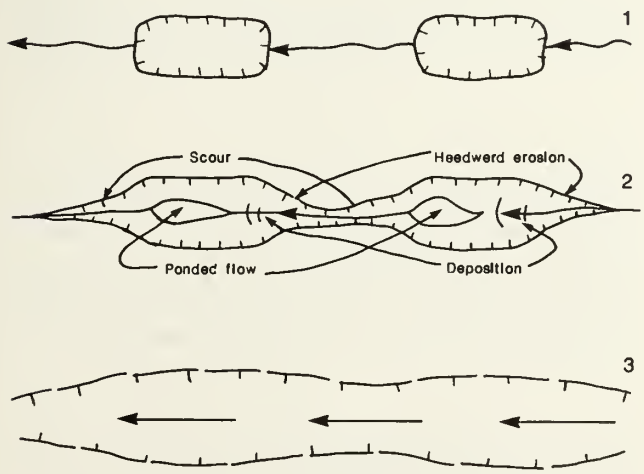


Figure 8. Headword erasian and scour resulting from deep pit in stream channel. *From Envicom Corporation, 1979, Santo Cloro River, sand and grovel extraction, Master EIR study, Finol Environmental Impact Report: Prepared for Venturo County Resource Management Agency.*

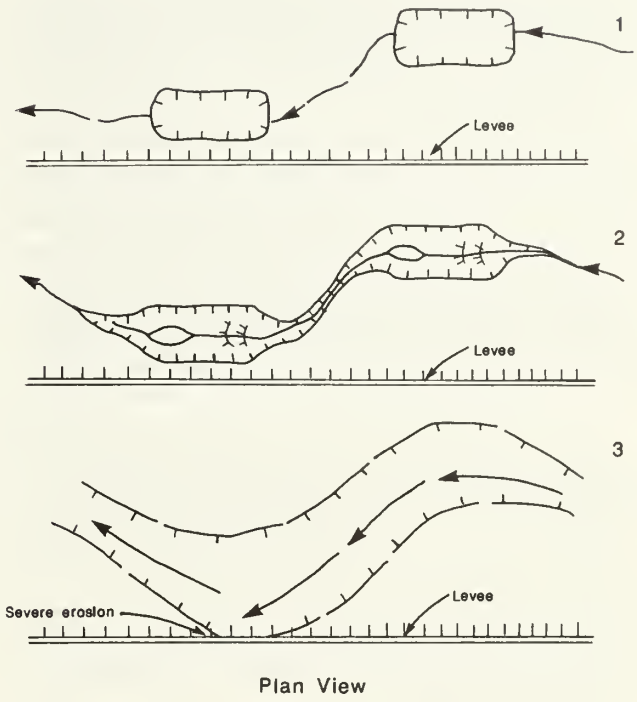


Figure 9. Headword erosion and scaur resulting from two offset pits in stream chonnel. *From Envicom Carporation, 1979, Sonto Clara River, sond and grovel extraction, Master EIR study, Final Environmental Impact Report: Prepared for Venturo County Resource Monagement Agency.*

Example Erosion Patterns. Unfortunately, it is often difficult to visualize the final stream configuration after mining, and its potential effects on stream erosion. Figures 6 through 11 show the locations of erosion-prone areas common to in-stream mining and the effects of differing final configurations on subsequent erosion and sedimentation near the site. As shown in Figures 6 through 11, the narrow, shallow and streamlined final pit configurations (Figures 7 and 11) have less widespread effects up and downstream than the wider and deeper configurations (Figures 6, 9, and 10).

Figure 8 shows common erosional results from a series of pits on a channel. As fall rains begin, the pits attempt to smooth the stream's longitudinal profile. This results in headward erosion and scour. Intervals between streamflows may see ponded water in the depressions. With the onset of flood flows, the individual ponds may no longer be identifiable, but the excavation's effect on the longitudinal profile and knickpoint migration may still be evident.

Figure 9 illustrates how the locations of pits can lead to flows being directed into a bank or levee. In this case, the pits have accentuated the normal meandering of the stream. The erosion is strongest at the outside bank of a curve, so the bank is aggressively eroded in the second pit.

Final stream configurations with gentle curves and slopes are less likely to lead to problems. In reviewing the plan and profile

drawings, the operator or reviewer should look carefully at the areas around any existing or proposed curves that are not very gentle. If potentially sensitive areas, e.g., banks or excavations, are, or will be present, special protection or mitigation should be proposed.

Flow direction shifts must also be considered in the reclamation process for sand and gravel operations that are not presently in an active channel, but are in regions such as adjacent floodplains, inactive channels in a braided river system, old meander loops (oxbows), or inactive alluvial fan distributaries that could become reactivated with natural erosion by the active channel. Unless anticipated and properly planned for in the reclamation process, an active channel might erode into a nearby pit on an adjacent channel causing sudden diversion of flow and erosion of both stream banks and beds.

A dramatic example of this process occurred in Tujunga Wash in southern California (Scott, 1973, and Bull and Scott, 1974). In 1969, the runoff flowing down Tujunga Wash eroded its historic main channel and broke through an unstabilized levee into a large sand and gravel pit located in an adjacent channel. The vertical scour resulting from the knickpoint migration of this adjacent channel caused the failure of three bridges. Lateral scour destroyed seven homes (Scott, 1973). If the potential reactivation of this channel had been recognized, the final pit configuration and levee design could have been modified to prevent or minimize these problems.

A record of one intermittent stream's reaction to the lowering of the streambed by in-stream sand and gravel extraction is shown in Figure 12. Here, mining lowered the streambed more

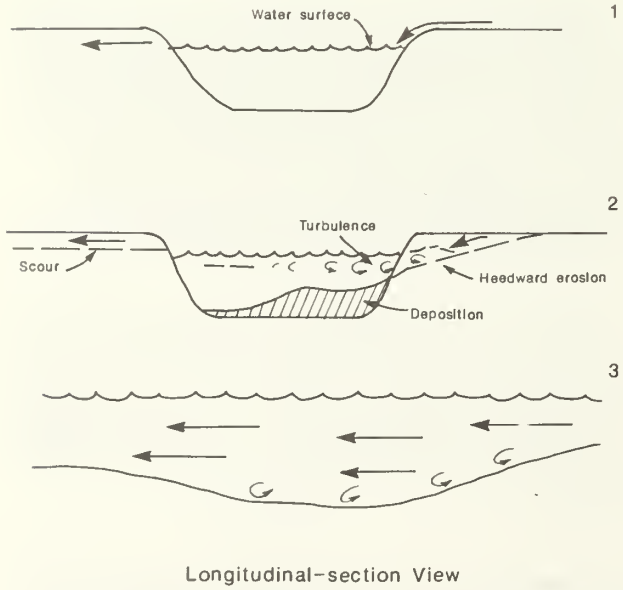


Figure 10. Headward erasian and scaur resulting fram twa in-line pits in streom channel. From Envicom Corparatian, 1979, Santa Clara River, sand and gravel extraction, Master EIR study, Final Environmental Impact Repart: Prepared for Ventura County Resource Management Agency.

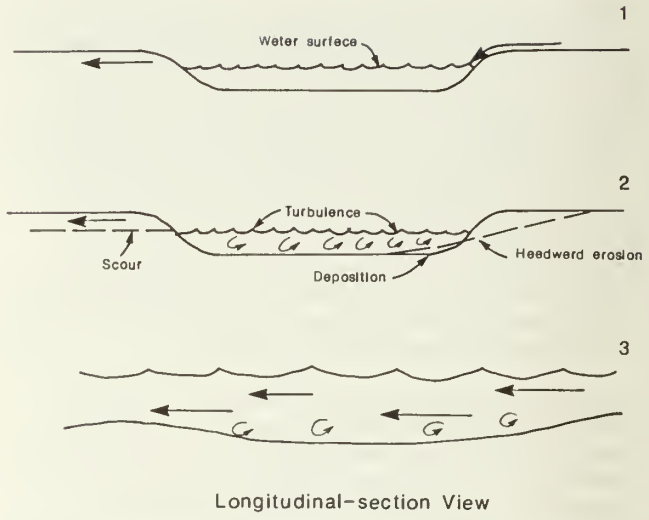


Figure 11. Headward erasian and scaur resulting fram shallow, elangate pit in stream channel. From Envicom Corporation, 1979, Santa Clara River, sand and gravel extraction, Master EIR study, Final Environmental Impact Report: Prepared far Ventura Caunty Resource Management Agency.

than 50 feet in the area of the pit. The initial flows into the pit eroded the headwall and deposited sediment in the area of least velocity. With subsequent flows, the knickpoint retreated farther upstream, eroding a greater area to produce a more uniform slope. Four years later, the effects of the knickpoint could be seen over 4,000 feet upstream from the original limits of the pit.

In this case, the depth of scour was limited by a semi-resistant sandstone bed underlying the channel. As upstream erosion proceeded, this bed acted as a gradient stabilizer. Stream reclamation techniques are often designed to mimic this desired effect.

Reclomotion Treotments to Reduce Erosion

A variety of treatments is available to stabilize stream systems that are adversely affected by in-stream mining. Many of these techniques, such as the placement of riprap, have been in use for hundreds of years. The success of the treatments, however, relies not only on the understanding of the method, but also on the understanding of the stream system for which it is to be used. In fact, improper design or use of these methods has often aggravated, rather than mitigated, stream stability problems.

The type of existing stream or river pattern should be considered in both the cross-sectional and longitudinal grading. Different channel patterns exhibit different slope, sediment and cross-sectional characteristics (Schumm, 1960, 1961; Schumm and Kahn, 1972). What is appropriate for a straight, high-velocity gravelly mountain stream may not be appropriate for a wide, meandering, slowly moving river.

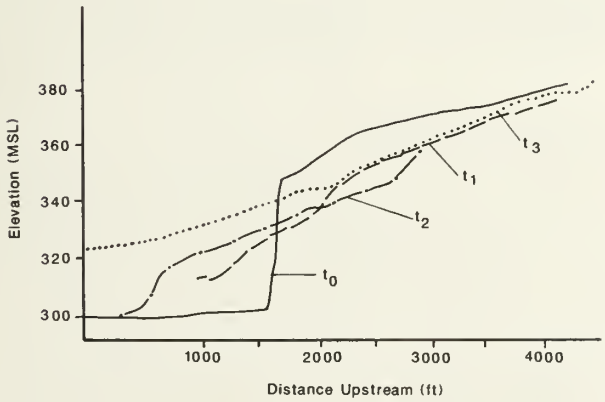
Grading Techniques. Grading of in-stream excavation slopes is a particularly important part of the reclamation processes, both from the standpoint of erosion control and aquatic/riparian habitat. Most reclamation plans, streambed alteration agreements

(issued by California Department of Fish and Game) and U.S. Army Corps of Engineers in-stream mining permits contain some sort of provision for this work.

Smoothing and sloping of the site is necessary to reduce long-term bank instability that could result from over-steepened pits, or bed lowering near the stream banks. A smooth, gentle cross-sectional and longitudinal slope will also minimize resistance to flow and reduce erosion of channel materials. In addition, uniform grading and slope toward the main channel will help to prevent fish entrapment with falling water levels. Another aspect of grading may also be partial replacement of a site's armoring layer with available waste rock. This may be a good way to dispose of over-size rock.

Timing. Many lead agencies in California have chosen to set fall or early winter deadlines for the completion of annual in-stream reclamation activities. These time frames are set in order to minimize the chance of flooding before reclamation is carried out. In general, the site should be sloped and contoured as soon as the operation is complete at the end of each mining season.

Cross-Sectional Grades. Selection of a cross-sectional grading program for in-stream mining reclamation should attempt to address bank stability, potential revegetation and levee protection, adequacy of design and maintenance. All of these factors are important to the long-term success of the plan.



t_0 = 4/10/74 and 6/7/76, excavation below channel bottom (thalweg)

t_1 = 2/6/78 channel bottom profile

t_2 = 2/21/78 channel bottom profile

t_3 = 3/4/78 channel bottom profile

Figure 12. Langitudinal profile showing migration of a sand-and-gravel pit knickpoint in San Juan Creek, Orange County, California. *From Li, R.M., and Simons, D.B., 1979, Mathematical modeling of erasion and sedimentation associated with in-stream gravel mining, p. 420-429, in* Conservation and utilizotion of water and energy resources: American Society of Civil Engineering, Hydraulics/Energy Division Conference, San Francisco, August 8-11, 1979.

A review of existing lead agency recommendations reveals a large variation in grading suggestions. Yolo County's interim In-Channel Surface Mining Regulations (February 28, 1979) specify a three-to-one (horizontal to vertical) slope measured perpendicular to the thalweg. Lake County's Creek Management Plan states that banks and cut-slopes within the active channel should not exceed 1.5 to 2.

Proposed final channel configurations involving channel constriction or narrowing should be discouraged. This may lead to both on- and off-site erosion.

Longitudinal Grades. Longitudinal grades should be chosen that minimize differences between the site's original condition and the proposed final configuration. If, for instance, pool and riffle sequences presently exist, a reclamation goal should be the re-establishment of a similar channel pattern.

This kind of mimicry will lessen the potential for upstream and downstream channel responses. Gradients at the upper and lower ends of the excavated area should be integrated as much as possible with the natural channel gradient in order to reduce erosion or deposition at those points.

Review of local agency regulations show that there are many different grading requirements, dependent to a large extent on the river system and whether or not the lead agency allows in-stream extraction below the thalweg or summer low-flow channel. Lake County is one that restricts all mining to levels above the thalweg. Yolo County, which also requires that mining be above the thalweg elevation, states that all longitudinal grades should be finished to a uniform maximum slope of ten-to-one measured parallel to the thalweg.

Structural Measures. Structural methods are often used to control bed and bank erosion. Table 2 lists those most commonly used. A report by Keefer and others (1980) provides 110 case studies illustrating these methods.

TABLE 2. *Countermeasures for stream erosion (from Keefer ond others, (1980).*

Purpose	Countermeasure
Chonnel Stobility	check dam
	cutoff-walls/drop structures
	culvert ond drop flume
	drop flume
	riprop
	revetments
	retords
	spurs
	rail bonk
	channel excovotion/realignment
	chonnel cleoring/widening
	continued maintenonce
Bridge Stability	culverts/inlet structures
	obutment protection
	pier protection
	structurol support
	bridge lengthening
	construction of new bridge

Costs for these measures will vary dramatically with the size and design of the structures, the location of riprap sources, sediment replenishment rate, channel configuration, potential degree of scour and other site-specific conditions. Cost estimates for Santa Clara River channel structures to protect channel intakes, bridges, and pipeline crossings varied from $3.5-7.0 million or $0.40 to $0.70 per ton of sand and gravel over 20 years (Envicom Corporation, 1979).

Other Hydraulic Effects of In-Stream Mining

Turbidity/Siltation. In-stream mining can result in elevated levels of turbidity and increased rates of siltation. Siltation of gravel beds smothers aquatic eggs, reduces benthic populations and reduces protective cover for larvae. Turbidity reduces light penetration into the stream water and diminishes the productivity of planktonic and benthic communities. Decreases in these communities will lead to a further loss in fisheries (Sorenson and others, 1977). Increased turbidity also significantly increases the cost of water purification for domestic use.

Reclamation treatments to control these potential adverse effects focus mainly on the three most common sources of sediment: (1) wash water; (2) disturbance within the channel; and (3) disturbance adjacent to the channel. As long as the process is kept isolated from the stream or river by berms, dikes, silt fences, etc., stockpiling and crushing should not create any increases in siltation. One of the most critical factors in the prevention of stream sedimentation, therefore, is careful planning of the operation with respect to the floodplain and stream system. High-water lines (or projected design floodplains) should be delineated in the reclamation planning process. Facilities, equipment, and settling ponds should be placed above the floodplain and/or behind secure berms or reclaimed or removed before the winter season and threat of flooding. Otherwise, there is the potential for adverse sedimentation derived from erosion of the site into the stream and vice versa. Stream crossings should be removed to prevent backup of flood water, build up of debris, and erosion caused by deflection of the water into adjacent stream blanks.

If it is necessary to locate the extraction site in an active stream channel, the live stream must be diverted and the existing channel bermed both up and downstream. Bain (1981) suggests that where excavation has occurred in a dry stream channel, elevated erosion levels might be found during the initial seasonal stream flows over the area, especially if an armoring layer has been disturbed.

The main waste products of sand and gravel washing are sediment and water. A U.S. Environmental Protection Agency study (Newport and Moyer, 1974) estimated a minimum of 600 gallons of water are required to remove clay, mud and other undesirable substances from one ton of sand and gravel. This water and the washed-out fine sediment need to be controlled and disposed of without adverse environmental effects. As was discussed in the previous chapter, this potential sediment contamination usually is controlled by use of settling ponds or basins.

Gasoline/Oil. Gasoline and oil spills resulting from fueling error or mechanical breakdowns can occur at in-stream sand and gravel sites. Disposal of these contaminants usually involves removal of the affected material and disposal at an approved site. In most cases, this entails scraping or dozing the contaminated sand and gravel from the site before runoff can disperse the spill and/or carry it into the stream system. Removal and disposal of this material should be discussed in the reclamation plan pursuant to SMARA, Section 2772(h).

Aquatic/Riparian Habitat

In-stream gravel operations may affect fish both directly and indirectly. Direct effects may include the removal of gravel in a spawning area and the turbidity that can clog fish gills. The indirect effects may include water temperature increases due to removal of streamside trees, upstream erosion from knickpoint migration, erosion downstream due to the reduced supply of sediment (sediment starvation) and ponding that can interrupt the migration of juvenile fish. The need to consider downstream effects is increased if there are multiple mining operations on the stream, because together they may remove more material than the stream can replace.

Many of the reclamation techniques discussed above are also applicable to the reclamation of aquatic and riparian habitat (SMARA, Section 2733). In general, contamination or degradation of water quality will adversely affect fish and habitat.

Additional treatments for maintenance or re-establishment of habitat center around: (1) re-establishment of pool/riffle sequences; (2) removal of fines which may be detrimental to spawning areas; and (3) revegetation of banks to provide cooling shade and food sources. Specific treatments to accomplish these goals are beyond the scope of this chapter, but Gore (1985) discusses specific measures to enhance fish habitat. The reclamation planner interested in these types of treatments should review appropriate literature referenced in the annotated bibliography published by the California Division of Mines and Geology (1984a), or consult with a biological specialist.

DATA NEEDS FOR THE SELECTION AND DESIGN OF RECLAMATION TREATMENTS

Development of an effective reclamation plan for in-stream mining, like all other mining, relies heavily on the availability of the necessary baseline data. Data requirements will, of course, vary with each stream system and operation. In general, however, data needs fall into the catagories of: (1) topographic and geomorphic information; (2) stream flow and sediment transport data; (3) hydrogeologic information; and (4) human influences. Much of this data can serve two purposes: input to the design of the reclamation plan, and protection for the operator against unwarranted claims of damage. Collection of background data relating to in-stream mining reclamation can be somewhat different from other types of mineral extraction in that it often involves a regional or cooperative effort. A significantly large extraction by one operator or by multiple operators on the system can have noticeable effects offsite in the drainage basin. Reclamation treatments to minimize these effects must take into account not only what the natural conditions are, but what other human activities may be affecting the stream system. This overview is sometimes most readily provided through a basin-wide study. These types of studies — commonly carried out by county, state or federal agencies, cooperative lead agencies and mining industry efforts or through a Master EIR/EIS approach — provide the necessary kind of coordinated overview. Discussion of data needs in reclamation planning for in-stream mining operations will, consequently, be divided by the size and number of operations on a stream system.

Small, Single-Site Operations

Small, single operations on a watershed, involving gravel-bar skimming or shallow excavation above the thalweg, present the least reclamation difficulties. Generally, these will not have a significant effect on either sediment replenishment to downstream areas or the position and elevation of the thalweg.

Data needs will center around a generalized knowledge of the river or stream system and topographic information. Site-specific information such as cross sections, longitudinal profiles, and extraction rates should be obtained to provide a clear idea of the operation and reclamation plan. Longitudinal profiles should be required for any operation that changes the existing low-flow channel. Cross-sectional profiles and supplementary flow direction profiles should be prepared where area changes are large, turns in the channel are sharp or other indications of potential problems described above are present.

Cross Sections: Cross sections of the stream channel and banks should be obtained by a registered civil engineer or licensed surveyor for all in-stream operations in order to document existing conditions and graphically show the proposed, final site conditions. These cross sections should be prepared from bank to bank (preferably showing the active floodplain), perpendicular to the direction of stream flow and referenced to permanent bench marks. Even the smallest operations should have one cross section above and one below the site as a base to determine if erosion is moving beyond the site. Key landmarks should be identified so that developing problems can be detected without the expense of periodic surveys. If the size of the project nears the average annual sediment-replenishment rate, or when the thalweg will be lowered, additional cross sections should be added. The number, location and length of the cross sections depend on the size of the project and the stream type, but the U.S. Fish and Wildlife Service generally recommends at least five cross sections; three or more of these would broadly describe the site, and one or more would be necessary up and downstream. In addition, it is recommended that supplemental cross sections be obtained at each area of significant change in floodplain width. The Yolo County In-Channel Surface Mining Regulations (Woodward-Clyde, 1976) advocates at least three cross sections obtained in the area of extraction, no more than 1,200 feet apart.

These cross sections should be obtained before extraction is begun. Then, they can be used to depict the existing conditions and those proposed as final contouring. If extraction is to be seasonal over several years, it is suggested that biannual surveys, done in the spring and fall, be completed each year to document the amount of sediment replenishment and the final conditions of the site at the close of the season.

This information is necessary in the reclamation planning process in order to estimate the type and extent of any stream bank or bed protection that might be needed. Changes in cross-sectional area of the stream channel or bank steepness, and flood protection proposed at the close of mining can be determined from these records.

Longitudinal Profiles: A longitudinal profile that depicts the lowest points in a stream or thalweg should also be completed before and after extraction. A profile of this sort will show if there is a proposed change in the streambed elevation, and help to refine any reclamation measures that might be called for.

Monitoring Records: To aid in implementing or adjusting the reclamation plan when operations are complete, monitoring records from the operating phase should be kept and made available. As a minimum, the quantities of material extracted and replenished each year should be measured or estimated.

Large or Numerous Operations on the Same Watershed

As in-stream mining has the potential to affect a much larger area than the actual extraction site, a comprehensive monitoring of cumulative effects is useful in watersheds with numerous or large operations. It is suggested that a comprehensive data collection system be established by the mining industry and lead agencies to evaluate historic, present and future hydrologic characteristics of the river channel(s). Several counties with significant in-stream mining (such as Lake, Sonoma, Yolo, Mendocino, and Ventura counties), have instituted this type of approach. These studies generally include both site-specific data, such as the cross sections and longitudinal sections discussed above, and more regional information related to fluvial geomorphology, hydrogeology, sediment replenishment and erosional history.

Human Influences on Sediment Replenishment: The reclamation planner must account for human, as well as natural, influences on in-stream processes. Reservoir construction, for instance, acts as an artificial stream-grade stabilizer, controlling stream downcutting above the dam and causing most coarse sediment to be deposited behind the dam. While this coarse (sand and gravel) deposition is often beneficial for upstream mining operations, the release of "cleaner," less sediment-laden water lessens sediment replenishment downstream and can aggravate erosion problems. If reclamation of in-stream operations downstream from a dam has not accounted for this change in sediment replenishment, the chosen reclamation methods may not be adequate.

Urbanization and logging, on the other hand, serve to increase runoff and sediment to a watershed. The increased sediment supply may, therefore, increase sediment replenishment, and decrease the need for reclamation measures within the active channel and floodplain areas. Thus, watershed land use and changing practices need to be closely examined in any estimation of historical and potential future sediment replenishment of a stream system.

Reclamation of in-stream mining sites should be closely tied with an evaluation of long-term effects of in-stream mining and reclamation on bridges, pipelines, channel protection works, diversion intakes, etc. Many of these structures can be severely damaged if undercut, scoured or buried by sediment. Inventory of all potential structures that may be affected by scour and deposition should therefore be a preliminary step in the reclamation planning process. Structural design information should be obtained and then evaluated in relation to the predicted long-term sedimentation and scour effects of the final pit configuration or estimated sediment replenishment rate.

CHAPTER 5: DATA SOURCES AND ANALYSIS METHODS

Data Sources and Data Collection Concepts

GENERAL DATA SOURCES FOR SURFACE WATERS

Hydrologic data is generally referenced by watershed, longitude and latitude (Figure 13), or township and range (Figure 14). The California Department of Water Resources has indexed data from various sources in:

> "Index to Sources of Hydrologic Data" California Department of Water Resources, 1981a, Bulletin 230-81, 696 pages.

Copies of this publication are available from:

State of California
Department of Water Resources
P.O. Box 388
Sacramento, CA 95802

Much of the information referenced in this publication, as well as annual updates to the publication, are available on microfiche through the Department of Water Resources.

The U.S. Geological Survey also provides hydrologic reference documents that are available in many larger libraries. The most recent series of U.S. Geological Survey hydrologic data publications "Water Data for California," is published annually for California in four regional volumes. Pre-1970 U.S. Geological Survey reports of California water quality and quantity data are entitled "Surface Water Supply of the United States" and "Quality of Surface Water of the United States."

The National Water Data Exchange (NAWDEX) is a program established by the U.S. Geological Survey in 1976 to catalogue and index national water data, and to improve access to this information. NAWDEX is a national association of water-oriented organizations formed to assist users of water data. It maintains two computerized data bases: (1) the Water Data Sources Directory and (2) the Master Water Data Index (Edwards, 1981).

The U.S. Geological Survey also administers the National Water Data Storage and Retrieval System (WATSTORE). This data base maintains files on: (1) daily or continuous surface water, quality of water, and groundwater data; (2) annual peak streamflow values and gage heights; (3) surface and groundwater chemical analyses; (4) water data parameters measured more frequently than daily; (5) geologic and inventory information for sites with well and groundwater data; and (6) water use summary data. Questions regarding the use and application of WATSTORE data may be answered by either the U.S. Geological Survey District Office in Sacramento or the National Water Data Exchange Office.

The U.S. Environmental Protection Agency maintains the Storage and Retrieval System (STORET). This data base includes data on chemical, physical, geological and radiochemical analyses of both surface and groundwater. Data is provided by several federal agencies and more than 40 state agencies. In California, the lead agency for STORET data is the State Water Resources Control Board.

If sufficient information is not available to determine appropriate surface water reclamation treatments, a data collection program may be necessary. Often reclamation data needs and collection can be integrated with an existing collection system mandated by a regulatory agency. The specifics of any proposed new data collection should therefore be coordinated with the appropriate regulatory agencies early in the process to minimize costs and maximize the usefulness of the data.

DELINEATION OF WATERSHEDS

The watershed is the basic unit for analyzing hydrologic processes. An initial step in reclamation planning should be the delineation of the various watersheds on and surrounding the mine site. These features can usually be determined from, and diagrammed on, a properly scaled topographic map of the site and local region. By defining the drainage divides, contributing runoff areas, basic directions of runoff flow and drainages, an elementary picture of the site's surface hydrology can be developed. This information can then be integrated with various initial mining proposals to estimate the large-scale changes in surface hydrology that will need to be addressed in the site's reclamation plan (SMARA Sections 2733, 2772). Many mining operations, for example, make changes in both the quantity and direction of runoff flow. Runoff that may have previously been dispersed in various directions over a vegetated area, or in several drainages, may be concentrated and channeled through the pit or around the operation. An example of change in drainage area and watershed characteristics is shown in Figure 15. Where these changes are significant, the reclamation program will need to focus on long-term treatments to control flooding and/or erosion due to the change in runoff characteristics.

The delineation of various drainages within and adjacent to the proposed site is important in determining appropriate sources of data. The U.S. Geological Survey, U.S. Environmental Protection Agency, California Department of Water Resources, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Department of Agriculture and U.S. Forest Service all collect stream-flow data on many California streams and rivers. This information is often available from regional offices of these agencies, county flood control or engineering departments and libraries.

RIVER STAGE AND DISCHARGE DATA

River stage and discharge information is necessary to establish both flood levels and sediment transport history. If these data are not available for a nearby gauging station maintained by the U.S. Geological Survey, Department of Water Resources, county, or other agency, it may be necessary to obtain it in the reclamation planning process. These measurements are taken at measured cross sections in order to determine the velocity, volume and elevation of various volumes of flow at the site. The U.S. Geological Survey or county engineer or flood control per-

FEBRUARY 1981

Figure 13. Areal designation of major drainage areas for California. *Modified from California Department of Water Resources, 1981b, Rainfall depth-duration frequency for California: California Department of Water Resources, Sacramento, December 1981, 38 p., plus 21 microfiche.*

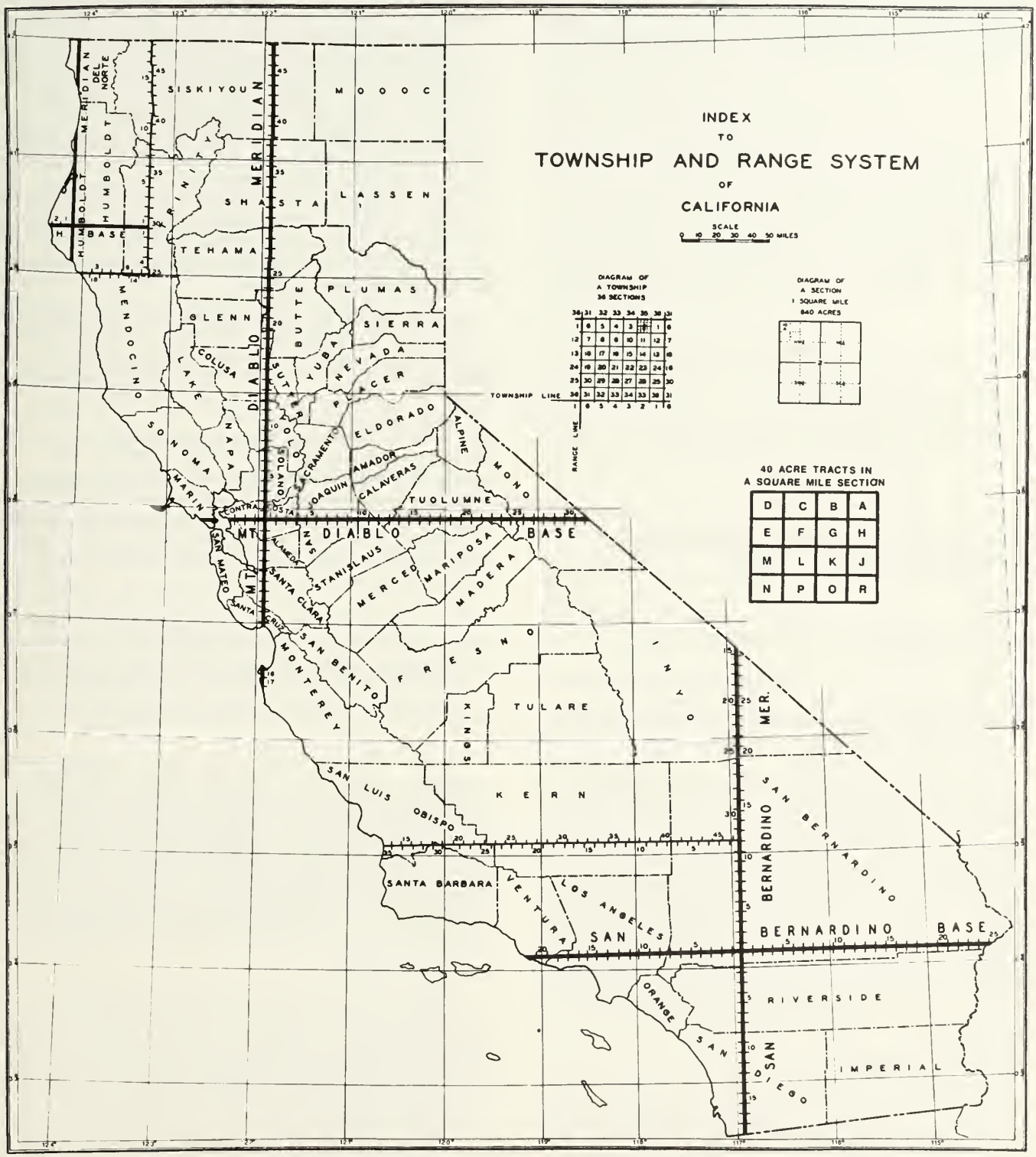


Figure 14. Index to Township and Range System. *From California Department of Water Resources, 1981b, Rainfall depth-duration frequency for California: California Department of Water Resources, Sacramento, December 1981, 38 p., plus 21 microfiche.*

sonnel can be contacted for information on previous and proposed data collection. Recommended literature sources describing procedure and analysis are Bovee and Milhous (1978) and Buchanan and Somers (1969).

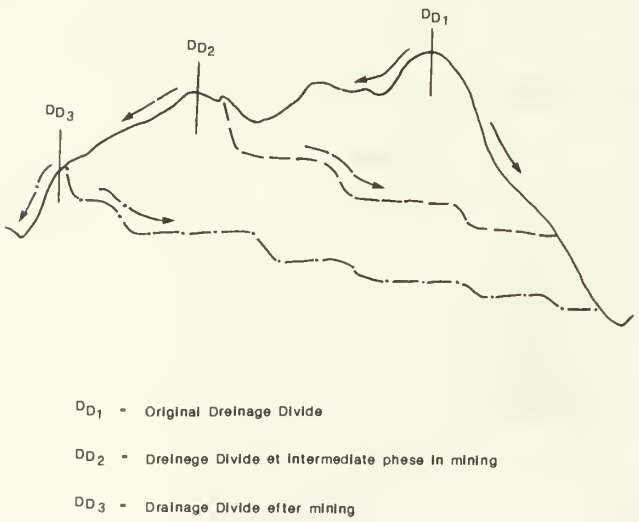


Figure 15. Hypothetical alteration of runoff (watershed) area due to development of the surface mine.

SEDIMENT TRANSPORT AND REPLENISHMENT RATE

Annual and long-term sediment replenishment rates are often some of the most useful, but most difficult estimates to make. Not the least of the problem is that actual physical measurement of the total sediment transport is very difficult.

Total sediment load is defined as the sum of two parts: one, the coarse material moving along the bed of the stream by rolling or saltating (bedload); and, two, the finer portion of the stream's sediment that moves suspended in the flowing water (suspended load or wash load). Techniques for measuring suspended concentrations, size distribution and suspended sediment loads have been well documented and are frequently used. Measurement or estimation of the bedload component of sediment discharge is much less precise than the calculation of suspended sediment load. Techniques for bedload measurements exist (Adams, 1979; Kellerhals and Bray, 1971; Osterkamp and Hedman, 1979), but differences between measured and computed values may be more than 100 percent (Wolman, 1977).

GROUNDWATER DATA

A preliminary step in reclamation planning should be the determination of a site's basic groundwater characteristics. For many operations and their reclamation, it is important to know (a) whether groundwater is present on the site; (b) how much (if any) there is; (c) where it is located with respect to possible groundwater barriers (such as faults, non-permeable units, etc.) and the proposed excavation and facilities; (d) with what speed and in which direction it moves; (e) what kind of quality exists; and (f) how much it varies from season to season, year to year, etc.

For reclamation planning, the primary groundwater concerns are changes in the quantity and quality of water reaching the aquifer. If the mining operation and final site conditions will be near the water table, or if there will be processing chemicals or waste materials that contain hazardous chemicals stored at or handled on the site, an assessment of the groundwater conditions is necessary. Thus, every reclamation plan should identify whether usable groundwaters underlie the site, and if so characterize groundwater occurrence and movement. If existing data indicate a possible drainage to groundwater that can be used for water supply or contribute to surface water uses such as fish habitat, an evaluation of the effects of the mining and reclamation on the quality of water recharged to the aquifer should be included in the reclamation plan. If chemicals that could degrade water quality will be handled or stored on site, then water quality issues should be addressed.

A number of state and federal agencies, such as the California Department of Water Resources, State Water Resources Control Board, Regional Water Quality Control Boards, and the U.S. Geological Survey, gather information on regional aquifers and groundwater characteristics. County planning, engineering or water departments may also be useful sources. These organizations should be contacted to obtain information that may provide an overview of the region's hydrogeologic conditions. Site-specific information is not usually available from these agencies unless significant well drilling or environmental documentation has been carried out on the site. Well logs of water wells drilled in California are recorded at the regional offices of the California Department of Water Resources and are available with the well-owner's permission.

The complexity of many groundwater systems in California and the general lack of long-term or specific data on individual aquifers often necessitate that a groundwater monitoring system be installed to predict both operational and reclamational needs of surface mines. In many cases, this data collection can be done simultaneously with initial exploration of the site.

Kaufman and Vandell (1983) suggest that groundwater data reconnaissance can be easily worked into the later phases of detailed mineral exploration to allow for essentially cost-free hydrogeologic information. As Kaufman and Vandell outline, drill-hole data obtained from a mineral exploration program can be used to design a "logical, defensible, and cost-effective baseline groundwater data reconnaissance" and well-monitoring program, if properly designed. A registered geologist or certified engineering geologist should supervise the logging of monitoring wells used to satisfy Regional Water Quality Control Board requirements.

Selection of compatible types of drilling and geologic/geophysical logging techniques in the exploration process can provide information on groundwater levels, permeability estimates, and water quality data with little additional cost to the exploration program. Data-collection costs saved by integrating this data collection program with exploration can be substantial.

An additional advantage to integrating groundwater monitoring at the earliest stages is that it allows the data collection to occur over a longer length of time. As with most hydrologic processes in California, a longer data collection program will usually provide a more accurate indication of the type of hydrologic variability. Knowledge of this variability may be the ultimate key to successfully addressing hydrologic concerns in the reclamation program.

To accurately characterize the existing conditions and those expected with proposed land use conditions, data collection programs may entail: (1) locating existing wells, lakes, ponds, streams, rivers, and springs; (2) analysis of drillers' well logs from wells on site and adjacent properties or logging of new wells; (3) basic geologic mapping to determine regional faults, fracture patterns, structural relationships and potential geologic units that could act as aquifers or aquicludes; (4) the use of geophysical methods such as electroconductivity or seismic reflection to determine subsurface characteristics over the site; (5) determination of groundwater levels over time; (6) hydrogeologic tests performed on site wells (for example, pump tests or slug tests) to determine aquifer properties such as transmissivity, storativity, heterogeneity, anisotropy, areal extent, thickness and recharge characteristics; (7) water quality sampling up-gradient and down-gradient; (8) evaluation of surface-groundwater interactions; and (9) determination of groundwater uses. A U.S. Forest Service report (Barrett and others, 1980) describes procedures for detailed studies. The appropriate Regional Water Quality Control Board should also be contacted for information.

Hydrologic Analysis Methods

For many of the hydrologic analyses needed in planning the reclamation of surface-mined lands, there are methods that have received wide acceptance. In some cases, several methods have gained acceptance among engineering geologists, engineers and planners. However, hydrology is not a precise and exactly determined science. The input precipitation and the conditions of the watershed are quite variable in both time and space. Hydrologic analyses provide estimates that are typical or probabilities of outcomes, but are not exact predictions. The results often must be used with discretion. Thus, when the methods indicate that the hydrologic response could cause significant adverse effects, a more thorough study by an expert is needed to identify the mitigation measures.

In this section, a few methods are presented that can be used to estimate the major items in hydrologic planning for surface mining sites. The methods may be used in preparing or reviewing a plan to estimate the general level of impacts that may be expected. The specific areas covered are the design storm precipatation, surface runoff, groundwater flow and erosion estimates. All of the methods can be performed by hand, but most are also available in computer programs.

In areas that are well instrumented with climatic stations and which demonstrate minimal orographic effects, it may be possible to get good estimates of a site's precipitation or other climatic parameters using one station's data or an arithmetic average of several stations. If comparison of station-to-station or site-to-station data shows significant variation exists, various numerical techniques can be applied to extrapolate or estimate long-term climatic data for the site. Explanations of some of these fairly simple techniques, such as the Thiessen weighted average, can be found in most general texts on hydrologic methods (for example, Linsley and others, 1975). More complex statistical approaches are available; however, if this degree of accuracy is necessary, a professional hydrologist or engineer may be needed to derive this information.

DESIGN STORM SELECTION

One of the most common tools for the evaluation of specific reclamation treatments is the "design storm." The term "design storm" refers to a precipitation event of a determined frequency or recurrence interval (10-year, 25-year, 100-year, etc.) and specific time duration (30 minutes, 24 hours, etc.). The design storm or storms for a project are usually described in terms of this duration and frequency or probability. For example, Figure 16 shows historical 24-hour rainfall intensity plotted against duration for several different recurrence intervals. The graph indicates that for this site a 24-hour rainfall event recurring, on the average, once every 25 years would be expected to equal or exceed an intensity of 0.2 inches per hour, or a total of 4.8 inches in 24 hours. Such an event would be called a 25-year, 24-hour event. It has a probability of occurring in any single year of 1 divided by 25 (the recurrence interval), or 0.04 (4%).

Decisions on the recurrence interval of a design storm and its duration should be made in conjunction with concerned local, state and federal agencies. Many of these agencies have suggested or required criteria for operational or reclamational treatments. The 25-year, 24-hour storm, for example, is specified by the Water Resources Control Board for diversion and drainage facilities in hazardous mining waste management.

General considerations for the selection of a design storm center on the proposed duration of the project and reclamation program, potential hazards associated with the project facility and anticipated long-term impacts to be handled by reclamation techniques. Theoretically, a cyanide tailings dam for a 100-year mining project on a site located above a domestic water supply reservoir would require protection from a much more infrequent, or longer duration, storm event than a one-year sediment pond in an uninhabited desert environment.

If the site's climatic record is short and/or erratic or statistically skewed, it may be difficult to develop reasonably accurate intensity-duration-frequency curves from which design storms can be chosen for the proposed reclamation treatments. A major limitation stems from the type of data that is generally available. Most climatic stations collect daily rainfall totals. The minority are equipped with continuous rainfall collections systems from which short-term, intensity-duration data (such as 30-minute, 25-year events) can be easily derived. The California Department of Water Resources (1976, p. 1-24) has developed regional data and procedures to estimate the intensity for different durations and frequencies. If the potential damage is not severe, the regional value may suffice for design of reclamation measures. If potential damage is large, the unique conditions (elevation, etc.) of the specific site must be considered.

Runoff, both onto and off of a site, can be a significant reclamation issue. Many aspects of a reclamation program rely on accurate estimation of runoff. Landshaping, impoundment design and erosion control measures must consider the amount and timing of runoff on the site.

There are several levels of runoff estimation that can be done to prepare a reclamation program, ranging from a simple correlation of runoff quantities with rainfall volume to complex computer modeling. The complexity of the analysis will, of course, depend on the level of detail necessary.

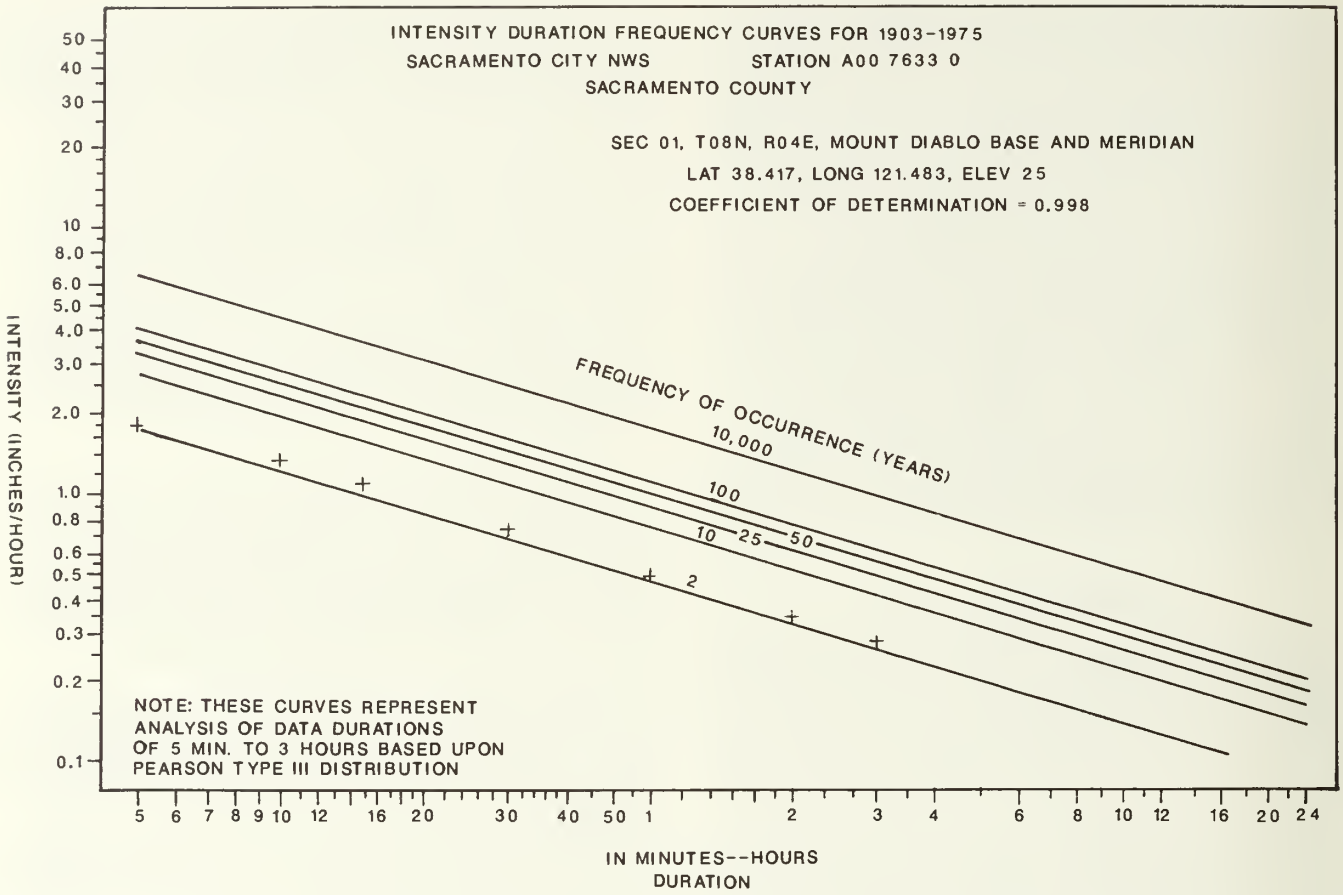


Figure 16. Rainfall intensity plotted against duration for different recurrence intervals. *From California Department of Water Resources, 1976, Rainfall analysis for drainage design, Vol. III: Intensity-duration-frequency curves, Bulletin No. 195, October, 295 p.*

Simpler methods should be considered to initially determine the relative volume of runoff anticipated at the site and basic alternative reclamation approaches. Selection of specific approaches may best be evaluated in a more detailed analysis.

THE RATIONAL RUNOFF METHOD

The Rational Runoff Method is a commonly used approach for rough estimation of the peak runoff rate on sites of less than 200 acres. Using a basic equation of:

$$Q_{pk} = C\ I\ A$$

where:

Q_{pk} = peak runoff rate (cfs);

C = the rational runoff coefficient (based on the drainage basin characteristics);

I = rainfall intensity (inches per hour);

A = drainage area (in acres); and

a table of values for "C" for particular site conditions, estimates of existing and proposed conditions can be derived. Values of "C" range from 0.1-0.3 for forest or park areas to 0.8-0.9 for paved areas.

This method has been most widely used for urban drainage design, so most "C" values relate to types of urban development. However, Hromadka (1983) reports that the County of San Diego also uses the SCS soil classes (see next section) in assigning "C" values. Some researches also have related "C" values to recurrence intervals and other factors. This type of analysis can be useful in designing basic water-control and erosion-prevention systems, culverts, sediment basins, etc. in addition to indicating overall potential levels of reclamation treatments that will be necessary (Dune and Leopold, 1978).

THE SCS RUNOFF METHOD

The U.S. Department of Agriculture, Soil Conservation Service (SCS) developed a procedure making use of more detailed data about soil, vegetation cover, etc. The procedure can be used to predict the peak flow, as the Rational Runoff Method does, or to predict the complete hydrograph or flow versus time response of the watershed. The SCS Method can be used for larger areas than the Rational Runoff Method. The SCS Method is described in several SCS publications, including Section 4, "Hydrology," of The National Engineering Handbook (U.S. Soil Conservation Service, 1971). A more easily used guide to the SCS Method has been prepared by McCuen (1982). McCuen

discusses several methods, all based on the soil and vegetation-cover data that forms the core of the SCS approach. The following discussion outlines the method. Refer to the SCS National Engineering Handbook or McCuen for more detail.

The SCS Method begins by classifying soils according to their minimum infiltration rates. Table 3 lists the infiltration ranges for each of the four soil groups. The SCS has identified many of the soils in each of the four soil groups. If the soil is not listed by the SCS, infiltration tests can be run on the soils.

TABLE 3. Infiltration capacity ranges for SCS soil groups (McCuen, 1982).

Soil Group	Minimum Infiltration (in/hr)
A	0.30-0.45
B	0.15-0.30
C	0.05-0.15
D	0 -0.05

The second element of the SCS Method is the "cover complex," which consists of the land use or cover crop and treatment practices such as contour farming and hydrologic condition (good, fair or poor). Because most of the cover complex tabulations by the SCS are for agricultural lands, finding a cover complex similar to the mining site may be difficult. The regional SCS offices, however, may have more information on local cover conditions. The SCS California District has developed supplemental information for use at several points in the SCS method.

For a given soil group and cover complex, an SCS table has a runoff "curve number." Using the curve number (CN) and the design rainfall, the volume of runoff or the peak flow rate can be found from a series of equations or charts, depending on the variation of method used.

The SCS Method is considerably more complex than the Rational Runoff Method, but it makes use of all the information that is likely to be available. In addition, there are other methods that fall between these two in complexity. The choice of method may depend in part on whether the potential effects justify the added effort. In addition, the availability of computer programs, discussed later in this section, may influence the choice of method.

FLOODING EVALUATION

Delineation of floodplains and estimation of potential flood flows are important aspects of the operational and reclamational planning process. It is to the benefit of both the operator and the public to provide isolation of mined land and facilities from flood flows. Most reclamation treatments similarly benefit from this approach. Flooding can seriously interrupt or destroy reclamation efforts. Re-established vegetation can be killed, tailings or waste material transported, and erosion heightened.

A design floodplain (or plains) should be defined for the flood levels of the design storm — for example, a 10-year, 24-hour storm; a 100-year, 24-hour storm; etc. The design storm for a project and its reclamation should be chosen that will satisfy the concerns of the public and meet the requirements of SMARA, the Regional Water Quality Control Board, the California Department of Fish and Game, and any other applicable local, state, or federal agency. Surface mining and reclamation should then either be restricted to areas outside this zone or subjected to specific treatments to minimize potential adverse effects. (In-stream mining reclamation treatments, which by definition occur mainly in the active flood plain, are discussed in Chapter 4.)

As with many other types of hydrologic evaluation discussed in this chapter, selection of a design storm and flood plain must be evaluated and used with respect to the length, adequacy, and consistency of the historical record, knowledge of changing land uses that might affect watershed runoff and proposed modification of the site during the operational and reclamational phases. California stream-flow data in particular is characterized by a generally short length of data collection, widely fluctuating or cyclic runoff periods and changing land uses (urbanization, logging and damming/water development, etc.). These factors may limit the usefulness of historical data for predictive purposes. In most cases, determination of the adequacy of the existing data, derivation of the design flood-flow discharge and estimation of the elevation of this discharge at the site will require a professional hydrologist, engineer or engineering geologist. In many areas, specific floodplains, such as the "hundred-year floodplain," are mapped by local planning agencies, engineering departments, the California Department of Water Resources, the U.S. Army Corps of Engineers or the U.S. Department of Housing and Urban Development. These agencies should be contacted for information on available floodplain mapping before new evaluations are pursued.

HYDROGRAPH DEVELOPMENT

When more information is needed than just the peak flow rate, flow hydrographs are commonly used. Hydrographs are graphs showing stage, discharge or other properties of flow with respect to time. An example of a typical hydrograph and its basic components, adapted from the U.S. Bureau of Reclamation (1977), is shown as Figure 17(a). The height of the curve on the vertical discharge axis indicates the volumetric flow rate at which runoff occurs. The figure also shows the rainfall, separated into "loss" and "excess rainfall." The "loss" is the infiltration, etc., that occur before surface runoff. The "excess rainfall" is what becomes surface runoff.

Hydrographs are used to estimate (1) a site's water balance (inflow versus outflow or precipitation versus runoff); (2) peak runoff of surface water for design of drainage controls (culverts, berms, levees, etc.); and (3) potential changes in a site's hydrologic characteristics that should be addressed through the reclamation process.

Figure 17(b) shows an idealized, triangular version of a hydrograph that can help illustrate some effects caused by surface mining. The rectangular shape represents an excess rainfall input. The volume of excess rainfall, represented by the area of the rectangle, is equal to the volume of surface runoff, represented by the area of the triangle. The area of the triangle is one-half the base times the height ($\frac{\text{base} \times \text{height}}{2}$), or one-half the time base T_b times the peak runoff Q_p ($\frac{T_b \times Q_p}{2}$). If mining

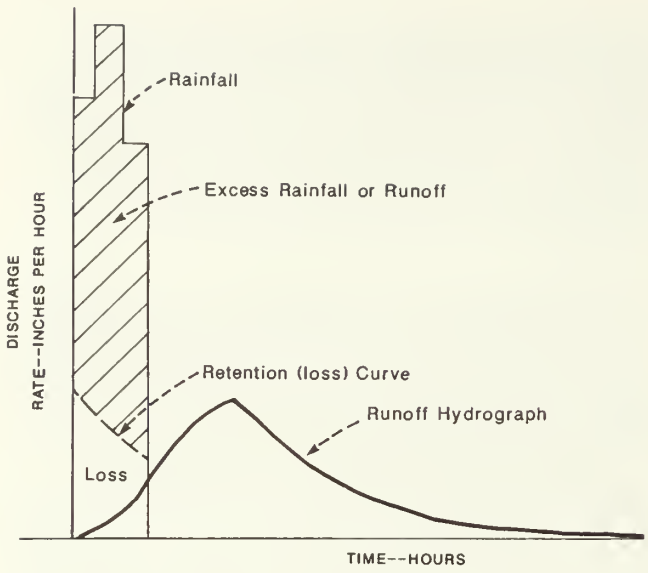
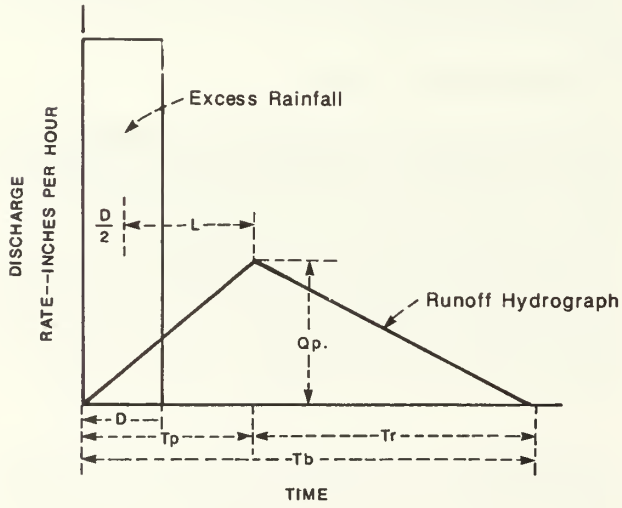


Figure 17(a) Typical storm-runoff hydragraph. *Modified from U.S. Bureau of Reclamation, 1977, Design of small dams; Chapter 3 Flood studies, Government Printing Office, Washington, D.C.*



Tp = time percolation
Tr = time runoff
Tb = time base
Qp = peak runoff
D = duration of storm
L = time lag characteristic of watershed

Figure 17(b). Ideolized triangular hydrograph. *Modified from U.S. Bureau of Reclamation, 1977, Design of small dams; Chapter 3 Flood studies, Government Printing Office, Washington, D.C.*

activities result in conditions, such as increased impermeable surfaces, and channelization speeding the surface runoff, the time base T_b would be shortened. For the same volume of surface runoff, the peak flow would have to increase. In addition, the more impermeable the surface area, the less infiltration "loss" and, consequently, the greater the volume of excess rainfall or surface runoff and the greater the peak runoff.

Conversely, measures that increase detention of surface runoff and lengthen the time base will reduce the peak flow. Retention ponds, flatter slopes and vegetation planting are examples of measures that slow the flow and lengthen the time base.

As shown in studies of strip mining, changes in peak flows (Q_p) resulting from mining depend on the magnitude of the storm analyzed, time of year, and amount of surface disturbance. In a case study reported by Overton and Meadows (1976), a contour mining operation, estimated to cover approximately 5 percent of the New River watershed in Tennessee, was researched. In the early stages of contour mining, peak flows were found to be significantly increased because high walls and benches intercepted runoff and routed it directly by ditches to surface streams. As mining in the study area intensified, the larger benches and pits were able to store significant quantities of precipitation, reducing overall peak flows and increasing the slow release of water to streams as subsurface seepage.

Hydrographs can be developed not only to document existing conditions, but to predict the effects of various reclamation proposals on a site's runoff. Comparison of pre-mining and predicted post-mining hydrographs can be a graphic way to present the site's hydrologic conditions and the effectiveness of proposed reclamation treatments. The SCS Method and some of the computer modeling methods discussed below are capable of estimating the complete runoff hydrograph for existing or proposed conditions.

STREAMFLOW CHANGES DUE TO CHANNEL ALTERATION

In analyzing the effects of channel alterations on streamflow conditions, the two equations commonly used are the equation of energy conservation and the Manning equation. The energy equation is applied between two locations along the stream surface. The equation is:

$$Z_1 + (V_1)^{2}/_{2g} = Z_2 + (V_2)^{2}/_{2g} + L\,S_f$$

Where Z_1, & Z_2 = surface elevations at points 1 and 2 relative to some common datum level;

V_1, + V_2 = average velocities;

g = gravity;

L = distance between points 1 and 2, measured along the stream channel; and

S_f = friction slope, commonly estimated using the Manning equation.

The Manning equation, using U.S. customary units of flows in cubic feet per second and distances in feet, is:

$$Q = \frac{1.49}{n} AR^{2/3}S_f^{1/2}$$

where Q = flow in cfs;

A = cross section area, in square feet;

n = a roughness factor depending on the channel side and bottom conditions;

R = hydraulic radius, or the ratio of the cross section (square feet) to the cross section length of contact between the water and the sides and bottom of the channel (feet); and

S_f = friction slope.

The friction slope indicates the rate at which energy is lost due to friction between the water and channel sides and bottom. Under equilibrium conditions (steady, uniform flow), the friction slope is the same as the longitudinal slope of the channel. But when changes occur, the two slopes can differ. When this occurs, the stream tries to re-establish equilibrium by changing the flow rate, friction slope or cross section conditions. For example, if the area of the channel is enlarged (which usually increases R as well), then the channel tries to increase the flow, decrease the slope or decrease the area. In a natural stream, all three may occur to some extent.

The effects of the streamflow adjustment are not always what is intuitively expected. For example, enlarging the area might be expected to lower the surface elevation of the water. But under fairly common conditions, the change in the friction slope leads to a rise in the surface elevation. This could aggravate flooding problems.

The combination of the energy equation with the Manning equation creates a non-linear form, involving integration, that cannot be solved analytically for the flow depth or surface water elevation. The usual approach to calculating these is to divide a stream into smaller segments and use average values of area and hydraulic radius to compute an average friction slope by the Manning equation. In the Standard Step Procedure, which is often used in computer programs, an iterative procedure is used to find the conditions at the end of each segment (U.S. Army Corps of Engineers, 1981a). The Direct Step Method (Linsley and Franzini, 1979) is simpler to use when conducting hand calculations. A water surface elevation is assumed and the distance to the end of that segment is calculated directly. The Direct Step Method applies to conditions where changes are gradual along the channel. It must be modified to an equivalent of the Standard Step Method if abrupt changes occur.

SLOPE EROSION

Erosion models have not achieved as much success as the hydrologic and streamflow models. Local conditions are so variable that even regional models are rare. The U.S. Soil Conservation Service (Wischmeier and Smith, 1978) has developed much information for its Universal Soil Loss Equation (USLE). The equation is simply an index form, but it has the virtue of pointing out the factors affecting erosion from general slopes. Beasley and others (1984) present a comprehensive discussion of the USLE. The equation is:

$$A = RKLSCP$$

where A = average erosion rate, in tons per acre per year;
R = rainfall factor;
K = soil erodibility factor;
L = a slope length factor;
S = steepness of slope factor;
C = crop or cover factor; and
P = erosion control practices factor.

Law (1984) states that the USLE was developed for agricultural conditions and that the values for the crop and erosion control practices need to be further developed. The other factors can give a basis for estimating how great a concern erosion could be and whether a more detailed study is justified.

SEDIMENT TRANSPORT/SAND AND GRAVEL REPLENISHMENT MODELS

The U.S. Geological Survey, U.S. Army Corps of Engineers, U.S. Soil Conservation Service and several independent researchers have developed numerical techniques to estimate gravel replenishment based upon suspended sediment measured in streams. These equations can have variable rates of accuracy and can be quite time consuming. To reduce the time of calculation and increase the accuracy, many of these equations have been integrated into computer models.

Sediment-transport models have come into increasing use in the last 15 years because of their application to a variety of managment issues, such as water diversion, dam construction, and channelization. Their application to California in-stream sand and gravel extraction, however, has been relatively recent.

The U.S. Army Corps of Engineers' Hydrologic Engineering Center's (HEC) HEC-6 sediment transport model has been proposed for use on several California watersheds to simulate the effects of sediment removal by in-stream extraction. It has been tested for use on a stretch of the Russian River in Sonoma County, and initial results indicate that the model can be useful in the study of sand and gravel extraction on a larger scale in this watershed (U.S. Army Corps of Engineers, 1982; Sonoma County Planning Department, 1981).

The model is designed to transport a "unit" of sediment mathematically from the beginning of the study reach to the end and account for sedimentation and scour along the way. Using channel cross sections and records of historical water and sediment discharge, changes in the river's cross section are modeled over time. Potential erosion and deposition of the channel's banks and beds can then be depicted for various scenarios of water flow and changes in the sediment budget, due, for example, to in-stream extraction.

Like many computer modeling methods, a general limitation of the HEC-6 scour and deposition model is the need for specific baseline data. In the case of the HEC-6 model, information is needed on watershed characteristics such as streambed elevations, geometry (in the form of cross sections), bed material graduation (at each cross section), inflowing sediment load, water discharge hydrographs for the reach and water temperature (U.S. Army Corps of Engineers, 1982).

Li and Simons (1979) developed a mathematical model for a San Juan Creek (Orange County, California) aggregate operation. The model routes sediment by size fraction and is capable of estimating the erosional and depositional response of an in-stream extraction pit to varying hydrologic and reclamational factors. In particular, the model was used to determine operational options and the effectiveness and placement of reclamation measures to control knickpoint migration. The modeled treatments included drop structures, gabions, and check dams. Comparison of these various alternatives, in this particular situation, showed that a series of small (2.5 foot) gabion dams would slow degradation of the streambed and control further headcutting once mining had ceased.

GROUNDWATER

Groundwater analysis methods include procedures to analyze well pumping tests to determine aquifer characteristics and prediction models for groundwater levels and movement. The well analysis methods are usually based on the Theis Method for unsteady flow to a well. This allows an analysis without waiting for steady-state conditions. Theis used an analogy to heat flow to develop a relation for flow to a single well:

$$Z = \frac{QW(u)}{12.6T}$$

where Z is the drawdown in an observation well for the pumping rate Q and the aquifer transmissivity T. The transmissivity relates to how easily water flows through the aquifer. The function W(u) depends on the aquifer characteristics tansmissivity and storage coefficient, the distance between the pumping well and the observation well and the time since pumping began. Theis developed a graphical procedure to match well pumping data to a "type curve" of W(u) and thereby determine the transmissivity and storage coefficient for observed values of drawdown, pumping rate, time and distance to an observation well (Linsley and Franzini, 1979; Barrett and others, 1980).

A modification of the Theis Method by Jacob is somewhat simpler, but still a graphical procedure (Everett, 1983). Aquifer characteristics vary considerably, so it is desirable to have an experienced groundwater hydrologist analyze well data in conjunction with well-log data and other geologic information.

Once the aquifer characteristics have been identified, there are numerous models to predict aquifer response to changes in recharge, pumping, etc. Some information can be obtained by using the well equation above or a direct application of Darcy's law, which is the basic equation for groundwater flow. The groundwater system is "linear" for water-level effects; so multiple wells, etc., can be examined by adding the effects the individual wells would have alone.

For a more detailed analysis, especially for water quality effects, computer models using finite differences and related methods are common. These models are beyond the scope of this report.

COMPUTER MODELING

Many efforts at modeling the quantity and quality of runoff characteristics in ungauged watersheds and/or disturbed lands have been carried out. The initiation of U.S. Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA) has been particularly instrumental in the advancement of the science, as the law requires characterization of premining and predicted post-mining surface water hydrology at mine sites. This information may include base flow, daily flow, and storm flow, as well as sediment loads and other water quality conditions. Section 779.13 of the regulations allow surface water modeling techniques, in addition to actual data collection, to furnish this information (Curwick and Jennings, 1981).

The U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC) has developed a number of hydrologic modeling programs. The HEC-6 model for sediment transport was discussed earlier. The HEC-1, Flood Hydrograph Package, has the SCS Method and several other hydrograph simulation options (U.S. Army Corps of Engineers, 1981b). The HEC-2, Water Surface Profiles, applies the Standard Step Procedure discussed above (U.S. Army Corps of Engineers, 1981a). The HEC-1 and HEC-2 programs are available for microcomputers as well as mainframes.

Hromadka (1983) presents computer programs for both the Rational Runoff Method and a hydrograph simulation approach. The specific procedures were developed for some local agencies in southern California, and have some features tailored to California conditions.

Groundwater models have received considerable attention in recent years. An American Geophysical Union publication reviews the available models for both quantity and quality management of groundwater (Bachmat and others, 1985). The U.S. Geological Survey has computer models for both quantity (Trescott and others, 1976) and quality (Konikow and Bredehoeft, 1978).

REFERENCES

The references specifically mentioned in the report are listed below. For most subjects, there are many other references that could have been added. The Division of Mines and Geology's 1984 report, "An Annotated Bibliography of Publications Pertaining to Surface Mined Land Reclamation," has key words and short descriptions to aid the reader's selection of useful reports. The current research literature also is extensive in the water management area.

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